Wax eggs as a method to identify predators and record interference rates in real and artificial nests of Banded Dotterel (*Charadrius bicinctus*) in braided river systems.

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The exposed gravel of the braided rivers of the eastern South Island of New Zealand provide nesting habitat for rare endemic bird species. These endemic bird species evolved in the absence of mammalian predators and it is suspected that predation by introduced predators is a major cause of species decline in braided rivers. Large scale monitoring of predation in braided rivers has mainly been confined to the Waitaki Basin, using video cameras. Further study of nest predation in braided rivers may require more economical monitoring techniques in order to cover more rivers and reduce the risk of financial loss through damaged or stolen equipment. Artificial eggs and nests have been widely used over the past two decades and have provided significant advances in nesting biology theory. However an increasing volume of research has shown that the results from artificial nests should be interpreted with caution as they may not sufficiently replicate the real nest situation.

This study provided an initial assessment of the utility of artificial wax eggs as a device to measure interference and artificial nests as a presentation technique for the wax eggs. There are several areas that were tested. Initially aspects of design were considered, did the wax egg need tying down, how should the wax eggs be tied, what strength of monofilament is appropriate, is a lure (natural egg) required to entice interference with the wax egg? Following this cryptically painted wax eggs were tested to replace the dyed wax eggs that had been used previously. Once the wax egg was designed it was trialled in both real Banded Dotterel and artificial nests. Overall rates of predation were compared between real and artificial nests along with the patterns of predation with respect to wax egg colour and location. The difference in predator suite recorded at real and artificial nests is also discussed.

This study found wax eggs were less likely to be lost if they were tied down. Failures of the tethers during Trial 2 were mitigated by increasing the breaking strain of the monofilament from 6.8 kg to 22.7 kg. Well-rooted vegetation (where available) was found to provide a more suitable anchor than rocks, although either were satisfactory. High rates of interference were observed on dyed wax, real quail and chicken eggs. It was decided that these rates of interference were too high to consider these egg types for use during the breeding season. Cryptically painted wax eggs were then trialled and found to not induce a strong response from the predators like that observed with the other egg types.

During the 2005 breeding season wax eggs were accepted by the majority of incubating adults and were seldom left unmarked following a predation event. However, in most cases predation could only be assigned to a predator group (avian or mammalian) rather than species, as the marks often lacked any clear distinguishing patterns for individual species. Impressions were identified to species level on seven occasions, two Black-backed Gulls and five Hedgehogs.

There was no significant difference between the overall predation rates observed at real and artificial nests. Artificial nests also showed similar effects of wax egg colour and location as real nests. However, there was a difference in the predator suite between real and artificial nests. The avian:mammal split for real nests was avian 17 (65%) and mammal 9 (35%) against the artificial nests 24 avian (96%) and mammal 1 (4%). These results highlight a problem with artificial nest experiments which is that although predation rates may be the same between real and artificial nests there may be a bias in predator type and that these biases may be counterbalancing. These results show further evidence that where possible artificial nest studies should be verified or calibrated with real nest data to assess there accuracy. The use of artificial nest should not be discounted because it has been shown to be inaccurate for some situations. For instance artificial nests may be appropriate where a species is highly endangered and therefore real nests simply are not available, or in situations where measuring of predator presence rather than effect on a target prey species is of primary interest.

KEY WORDS: Banded Dotterel, *Charadrius bicinctus*, artificial nests, real nests, nest predation, New Zealand, wax eggs, microcrystalline wax

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1.1 Braided River Biota

Braided rivers only form in mountainous, glaciated areas where natural gravel production, river flows and gentle gradients allow them to form. New Zealand is amongst only a handful of areas (India, Iceland, Tibet, Siberia, Alaska and Argentina) where the conditions produce braided rivers (Keey, 2005). The ever changing nature of the riverbed as channels form and reform provides a dynamic system that nurtures a unique community of plants, birds, fish, lizards and invertebrate life (Peat & Patrick, 2001). There have been over 20 species of wetland bird recorded on braided rivers in New Zealand. Of these, Wrybills (*Anarhynchus frontalis* Quoy and Gaimard), Black Stilt (*Himantopus novaezelandiae* Gould), Banded Dotterel (*Charadrius bicinctus* Jardine and Selby 1827), South Island Pied Oystercatcher (*Haematopus ostralegus finschi* Martens), Black-fronted Tern (*Sterna albostriata* Gray), and Black-billed Gull (*Larus bulleri* Hutton) breed mainly in braided river beds and associated habitats (Maloney, 1999). The Black Stilt is critically endangered, the Black-Fronted Tern is endangered and both Wrybills and Black-Billed Gulls are vulnerable (Keey, 2005). Banded Dotterel share habitat with these species and their relative abundance (pop. 50,000+ individuals) allow study of predation on their nests as a proxy for more threatened species.

Introduced predators have been implicated as a major cause of extinction and decline in both range size and abundance of native avifauna on islands (Sanders & Maloney, 2002). Nest predation is a major source of nest failure and, therefore, an important factor affecting bird breeding success and possibly in regulating their populations (Picman, 1987; Reitsma *et al.*, 1990; Major, 1991; Rebergen *et al.*, 1998). Nest predation is often a strong agent of selection on bird species and assemblages; it can influence life history traits (Picman, 1987; Svagelj *et al.*, 2003), habitat use, and population and community patterns (Martin, 1987; Part & Wretenberg, 2002). For these reasons knowledge of the predator species and the factors determining nest predation are required for successful avian population management.

Predation has been found to be the main cause of failure in Banded Dotterel nests (Sanders & Maloney, 2002). Rebergen (1998) observed high rates of predation on eggs and low fledging success, suggesting that breeding success is strongly affected by predation. Rebergen (1998) found that predation rates were comparable in the rarer riverbed species, indicating that predator management could be vital in managing endangered populations.

The future of these braided river systems (an ecological taonga or treasure) is uncertain as pressure grows for hydroelectric schemes and irrigation. Hydroelectric schemes have major impacts on braided rivers, reducing natural flow variability, exposing islands and allowing weed invasion (Rawlings, 1993; Keey, 2005). In 2004 the Ministry of Economic Development announced that 14 hydroelectric power projects had a medium to high likelihood of being developed in over the next 20 years (Keey, 2005).

Crack willow, gorse, broom, lupins and wilding trees are exotic weeds which are seriously degrading the ecological value of braided rivers. The root systems of these weeds stabilise the gravel confining the normally shifting channels and limit the ability of floods to flush the habitat clean. These exotic weeds also result in two other impacts, firstly, it increases the density of rabbits which supports a higher population of predators, and secondly provide cover for predators to hunt more effectively (Heppelthwaite, 1999).

1.2 Banded Dotterel

The Banded Dotterel is a relatively common, small, endemic plover that breeds in open habitat including braided riverbeds (Keedwell & Sanders, 2002). Banded Dotterels are approximately 18-20 cm tall (Falla *et al.*, 1966; Moon, 1994; Heather *et al.*, 1996). The dimensions of their eggs are usually 34×25 mm and they weigh

approximately 12 g (Heather *et al.*, 1996) and the normal clutch size is three (Falla *et al.*, 1966; Moon, 1994). Banded Dotterels nest between August and January (Falla *et al.*, 1966; Moon, 1994; Heather *et al.*, 1996). Both sexes share the incubation and various estimates of incubation duration fall between 25-30 days (Falla *et al.*, 1966; Moon, 1994; Heather *et al.*, 1996). Banded dotterels nest throughout New Zealand in a broad range of habitats, both coastal and inland, including inland shingle riverbeds and river terraces, inland gravel lakeshores, sub alpine herbfields, coastal riverbeds, river mouths, sandy and gravel beaches, coastal lagoons, estuaries and pastures (Falla *et al.*, 1966; Medway, 2000).

The nesting sites of Banded Dotterels on braided rivers are vulnerable to variable river flows, encroachment by introduced plants and introduced mammalian predators (Medway, 2000). In addition the encroachment of introduced plants such as willow, gorse, broom and lupin, has seriously degraded the value of some feeding habitat on the braided riverbeds of the eastern South Island (Medway, 2000). Such vegetation provides cover for predators, reducing breeding success and decreases available breeding habitat because Banded Dotterel tend to avoid nesting amongst vegetation (Crossland, pers. comm.).

The Banded Dotterel diet includes terrestrial and aquatic invertebrates, supplemented by occasional berries of prostrate plants. On pasture and tilled ground, they mainly take earthworms and beetles. On riverbeds, marshturf habitats of lakeshores and estuarine mudflats, they take worms, the larvae of chironomids, mayflies and caddisflies, and emerging adult insects. Like all plovers they feed visually by using run-stop-look-step-peck on dry sand and run-stop-peck on wet sand and saltmarsh, they also foot-tremble in damp habitats (Heather *et al.*, 1996).

Banded Dotterels, although not threatened with extinction, are subject to similar conditions as endangered species. They may serve as a useful species to model life history issues in a braided river system. In the present study Banded Dotterel is used as the experimental species to trial a technique for monitoring nest predation.

1.3 Nest Predator Monitoring and Analyses

Accurate predator identification is a key step in endangered species management. Predator identification helps to ensure predator control is targeted effectively, i.e. the most important predators (both financially and economically) rather than simply those present are targeted. Several techniques are used to varying degrees to quantify the causes of nest mortality, including hair traps, and imprints in plasticine, or wax eggs (Major, 1991; Pasitschniak-Arts & Messier, 1995; Davison & Bollinger, 2000; Svagelj *et al.*, 2003), bite marks on carcasses (Lyver, 2000), use of automated still cameras (Picman, 1987; Major & Gowing, 1994; Bayne *et al.*, 1997), and video camera systems (Sanders & Maloney, 2002; Stake & Cimprich, 2003; Thompson & Burhans, 2004). Sanders & Maloney (2002) provide the main source of data relating to nest predators on braided rivers in New Zealand. Their work involved a 5-year (1994-1999) video study of ground-nesting birds in the Upper Waitaki Basin. Rebergen (1998) used direct observation during the 1992 season to assess breeding success and predation at Banded Dotterel nests.

Historically avian nest survival analyses have involved simple measures of apparent nest survival or Mayfield constant-nest-survival models (Dinsmore *et al.*, 2002). New approaches such as program MARK (White & Burnham, 1999; Dinsmore *et al.*, 2002) and the logistic-exposure model (Shaffer, 2004), provide more powerful analytical tools.

In the present study artificial wax eggs were chosen as a means to identify predators. Wax eggs were made from microcrystalline wax which is produced by de-oiling petrolatum. Microcrystalline wax is generally darker, more viscous, denser, tackier, and more elastic and has a higher melting point than paraffin wax. These properties and it's apparent low palatability, result in bite marks from predators which are of high quality, usually allowing identification of species without the predator consuming the evidence (Thomas *et al.*, 2002a; Thomas, 2005a). Wax eggs have not been used in the braided river ecosystem before and this study is a first attempt to assess their suitability as a method to measure interference at nests.

1.4 Goal

- To establish the viability of artificial wax eggs as a tool for predator species identification and monitoring nest predation rates.

1.5 Objectives

1.5.1 Chapter 2

- Establish and describe a method to produce artificial wax eggs.
    - To test whether or not the artificial wax eggs need to be tied down.
    - To test whether the artificial nests will need a lure (e.g. quail eggs) to attract predators.
    - Adapt wax egg design and artificial nest layout and design as necessary to ensure the wax egg used during the breeding season is unlikely to increase predation at Banded Dotterel nests.

1.5.2 Chapter 3

- Examine whether predation at nests can be inferred from damage to artificial wax eggs and whether that damage can be used to accurately identify predator species.
- Investigate whether artificial nests are a satisfactory surrogate for real nests, with respect to the rates and patterns of predation.
    - Are survival rates of artificial nests baited with wax eggs equal to those of real Banded Dotterel nests baited with wax eggs?
    - Is the predator suite the same between artificial and real nests?
    - Does the colour of the wax egg effect the survival rate or predator species?
    - Does survival rate differ between the high disturbance (recreational and industrial) area (Location 1) and low disturbance (Location 2)?

Chapter 2: Artificial Wax Egg Development

2.1 Abstract

The presence of predators is often inferred using interference devices such as hair traps, tracking tunnels or wax blocks. In the past two decades a considerable quantity of research has been published which uses interference devices to assess nest predation. Much of this research uses quail (*Coturnix coturnix L.*) eggs as the 'device' to indicate interference. The quail eggs are usually placed in artificial nests spread throughout the study area and checked periodically. It has been shown that this is not sufficient to provide reliable inferences regarding the predation of real nests. Microcrystalline wax is a possible alternative to quail eggs. It is less brittle than paraffin wax, sometimes used to obtain predator bite marks, and has a low palatability (reducing the risk of predator consumption). These factors make microcrystalline wax an excellent material to use where predator identification is desired. This chapter follows the development and testing of an experimental method with an 'adaptive management' approach with the results of each trial driving the direction for the next.

A wax egg was created that could be used in artificial nests and also added to real Banded Dotterel nests during incubation. Trial 1, 2 and 3 used wax eggs dyed pale green. These trials test the need for quail eggs in artificial nests to stimulate predator interference and tethers to prevent removal of wax eggs by predators. In Trial 4 the interference rates on painted wax eggs with a cream base colour and brown and black 'splotches' were compared with chicken (*Gallus domesticus*) eggs to find out if cryptically painted eggs were interfered with at a more realistic rate than observed with dyed wax eggs and quail eggs.

Throughout all trials dyed wax eggs, real quail and chicken eggs were interfered with at high rates. In Trial 4, painted wax eggs were interfered with infrequently throughout a 24 day period, whereas large proportions of the chicken eggs were interfered with on days 3, 8 and 10 during this period. The impressions on the wax eggs, footprints, scat and shell fragments suggest the majority of interference

events involve avian predators. Also, fewer wax eggs were lost when tethers were used, although some tethers did fail and some reasons and mitigating techniques are discussed.

Avian predators in the Waimakariri River may be readily able to locate unprotected eggs like those used during these Trials. The reduced interference on painted eggs (Trial 4) indicated that although the predators were still present in the area, the painted wax eggs did not induce predation in the way that the dyed eggs had. The painted wax eggs were then used with tethering to monitor predation throughout the Banded Dotterel breeding season (Chapter 3).

2.2 Introduction

Nest predation is a major source of nest failure and, therefore, an important factor affecting bird breeding success and in regulating their populations (Picman, 1987; Reitsma *et al.*, 1990; Major, 1991; Rebergen *et al.*, 1998). Of particular importance is the effect of nest predation on endangered riverbed nesting birds. Predation is the main cause of failure of Banded Dotterel nests and high predation rates of eggs and low fledging rate of chicks suggest that predation strongly affects Banded Dotterel breeding success (Rebergen *et al.*, 1998). Therefore, monitoring nest predation of riverbed nesting birds in New Zealand may have important conservation significance.

Artificial nest studies have contributed significantly to nesting biology theory over the past two decades. However, no single method can be applied successfully to all nesting scenarios. In fact rarely have artificial nest method results been verified against real nests to ensure the accuracy of the artificial technique (Willebrand & Marcstrom, 1988). Quail eggs and artificial nests have become a common method of assessing predation risk for nesting passerine birds (Reitsma *et al.*, 1990; Bayne & Hobson, 1999; King *et al.*, 1999). Faaborg (2004) believes David Wilcove (1985) my have triggered the recent explosion of artificial nest studies. Artificial nest studies often use wicker baskets as artificial nests and quail eggs as surrogates. The idea is that an 'experimental nest' can be used to replicate the real nest of a target species or

substitute for an assemblage of species and that predation rates and predator species approximate those of the target species. Some early studies give warnings regarding the artificial nest methodology, '*these experiments demonstrate that some definite biases are associated with the use of artificial wicker nests to test predation rates and that these biases are not necessarily consistent among nest types or areas*' (Martin, 1987) and '*we conclude predation on dummy nests is a poor index of predation on natural nests of Eurasian Black-Grouse and probably overestimates the importance of bird predation*' (Willebrand & Marcstrom, 1988). Further evidence is accumulating showing that artificial monitoring techniques often do not accurately estimate predation on real nests (Moore & Robinson, 2004).

There are several areas that must be considered in the development of an artificial nest monitoring method suitable to each unique situation. In particular it should be noted that the sheer volume of publications using quail eggs does not prove them to be a standard method. There is one major failing associated with the use of quail eggs. When quail eggs are used the technique is biased against small predators that are unable to destroy large, thick-shelled quail eggs but that are capable of breaking small passerine eggs (Major & Kendal, 1996; Bayne *et al.*, 1997; Bayne & Hobson, 1999; Buler & Hamilton, 2000; Thompson & Burhans, 2004). To avoid this bias, many studies use eggs made of modelling clay that can be readily marked by small predators. Unfortunately, modelling clay has an odour that may influence predator behaviour (Rangen *et al.*, 2000) and clay eggs have been found to soften at high temperatures, which may affect the size of a predator's imprint and, therefore, cause its misidentification (Fulton & Ford, 2003).

Bayne & Hobson (1999) found through photographic evidence taken at artificial nests containing both quail and clay eggs that most predators destroyed both eggs. An exception was deer mice (*Peromyscus maniculatus* Wagner, 1845), which commonly destroyed clay eggs but were incapable of destroying quail eggs. It would appear that concern over a predator species inability to damage quail eggs is only warranted when small predators are known to be involved. Bayne & Hobson (1999) also found if damage to quail eggs was used as the measure of predation the presence or absence of

a clay odour had no effect on predation rate. Bayne & Hobson (1999) concluded that clay eggs were a good substitute if small predators are not involved and recommend that both real and clay eggs be used in the same nest. However, the use of modelling clay started in order to get measurements of those small predators and the use of both in the same nest can result in a problem observed by Thompson & Burhans (2004). They used plasticine, essentially the same as modelling clay, and found that sometimes mice would leave marks on the plasticine however it was raccoons that were removing the quail egg. So species identifications could be wrong in some situations if Bayne and Hobsons' (1999) recommendations were adopted that real and clay eggs be used in the same nest.

Svagelj *et al.*, (2003) looked at the effect of egg type on nest predation. They compared predation at Brown-and-yellow Marshbird (*Pseudoleistes virescens*) nests to experimental nests with either Japanese Quail (*Coturnix coturnix*) or Shiny Cowbird (*Molothrus bonariensis*) eggs. Svagelj *et al.*, (2003) found that nests baited with quail eggs did not approximate nest predation rates at marshbird nests and concluded that nests baited with quail eggs were not adequate for estimating nest predation risk, however, nests baited with cowbird eggs had similar nest predation and egg loss to active marshbird nests.

Both Thompson & Burhans (2004) and Part &Wretenberg (2002) found that artificial nests with plasticine eggs could not be used reliably to identify predators. However, Part & Wretenberg (2002) found nest predation on artificial nests did predict relative predation risk for real nests when quail egg depredation was used as the criterion for artificial nest predation. The higher predation of nests with plasticine eggs may have resulted because small mammals, relying on olfactory cues, comprised a large portion of the predator assemblage (Rangen *et al.*, 2000).

In summary, existing literature has highlighted that potential problems with nest concealment, egg visibility, and egg odours must be resolved to enhance the design and reliability of artificial nest experiments (Rangen *et al.*, 2000). Nest concealment is a common issue with songbird nests as conspicuousness varies with nest height and

substrate and silhouettes of artificial nests may be more conspicuous than real nests despite the best attempts at concealment (Rangen *et al.*, 2000). This was of little consequence in my study as all nests were on the ground and little nest material was involved. Quail eggs or plasticine eggs are usually a poor mimic of the target species actual egg, potentially resulting in a difference in the egg visibility. I combated this with a realistic looking wax mimic.

In this initial study phase mimics of Banded Dotterel eggs were created, and placed in spatially contiguous areas of Banded Dotterel nesting habitat prior to the breeding season. The trials discussed in this chapter deal with the steps used to develop the wax egg technique for use during the breeding season. Key issues that required addressing were: whether or not predators would interfere with wax eggs and whether a lure (quail egg) would be required to incite interference, and would wax eggs be lost if left unrestrained. The process of making the wax eggs and the effect of change in appearance is also discussed.

2.2.1 Objectives

- Establish and describe a method to produce artificial wax eggs.
- To test whether or not the artificial wax eggs need to be tied down.
- To test whether the artificial nests will need a lure (e.g. quail eggs) to attract predators.
- Adapt wax egg design and artificial nest layout and design as necessary to ensure the wax egg used during the breeding season is unlikely to increase predation at Banded Dotterel nests

2.3 Methods

2.3.1 Study Site

The study area for all experiments was the riverbed of the Lower Waimakariri River, primarily upstream from the State Highway 1 Bridge, where the braided river type begins. During 1999 and 2001 bird surveys were conducted on the Lower Waimakariri by Christchurch City Council staff (Crossland, pers comm.). During the spring of 1999, 38 pairs of Banded Dotterels were observed between Crossbank and the River Mouth. In 2001, 67 pairs were observed between Crossbank and Weedons-Ross Rd. The condition of the riverbed was found to be very good with multiple braids and a range of micro-habitats suiting the requirements of most riverbed bird species. Vegetation encroachment has been observed to be far less widespread than on many other lowland rivers (Waipara, Ashley, Selwyn, Ashburton, Hinds, Opihi, Orari and Waitaki) (Crossland, pers comm.).

2.3.2 Trial 1

2.3.2.1 Development of the wax egg for Trial 1

Microcrystalline wax (from Pest Control Research Ltd) was used exclusively throughout this research as the artificial egg material. The wax was melted in a water bath (a large billy can on an electric stove). The wax was melted in a Cucinaware® (model: euro) 1000 ml coffee plunger with the top and plunger apparatus removed. This vessel held approximately the amount of wax needed, transferred the heat quickly to melt the wax and had a plastic handle so it did not get too hot. The quartz glass of the coffee plunger became brittle and cracked after being heated and cooled about 30 times, so the quartz glass was replaced with a Pyrex beaker (Figure 2.1). The wax was heated to approximately 70°C and poured into plastic Easter egg half moulds (E13 small plain eggs from Home Chocolate Factory,

http://members.aol.com/chocshop/). The mould dimensions were 34.92 mm x 22.22 mm. The temperature of the wax was monitored (Avanti® candy/deep fry thermometer) to avoid the plastic moulds being warped by the hot wax. Moulds were sprayed with silicone spray (CRC® 808 Silicone Spray) prior to the wax being poured to stop the wax sticking to the mould. Once the moulds were filled they were chilled in a freezer. The freezing shrank the wax slightly making it easier to remove from the mould. The wax was then left to return to approximately room temperature at which point a roughly 20 cm length of tie wire (Zenith® galvanised tie wire 22G x 80M), was bent into a hook and inserted into a wax half. The wax half was then dipped into molten wax. For this trial paper labels with a unique number were put between the halves of each egg. Each unique number could then be assigned to a specific nest. The hot wax was usually sticky enough to hold the two halves together long enough so they could be dipped back into the molten wax to seal the wax egg. The number of times an egg was dipped varied due to the temperature of the molten wax, the cooler the wax the thicker each sealing coat would be. At this point the egg shape was formed. Each wax egg was then allowed to dry and cool. Each wax egg was dipped into a second coffee plunger of wax which this time had been dyed using candle wax dye blocks (Arbee Craft candle colour blocks) to mimic the pale green base colour of many Banded Dotterel eggs. Once dry the remaining wire was either cut off (untied treatment) or wound into a loop (tied down treatment). Eggs were then labelled twice on the base of the egg in permanent marker with their nest number. Once created the eggs were stored in individual ziplock bags for each nest, except for a 36 hr period where eggs were left outside to weather to help reduce potential odour effects.

Figure 2.1. Electric stove and billy can for the water bath with coffee plunger (Pyrex beaker) to melt wax and thermometer to monitor wax temperature.

2.3.2.2 Trial 1 Experimental Setup

In this trial there were four different types of nest treatments (Figure 2.2) looking at two potential issues:

- Would a real egg (Quail egg) be required in the nest to induce predation?
- Would the artificial wax egg need to be tied down to prevent its removal from the nest area?

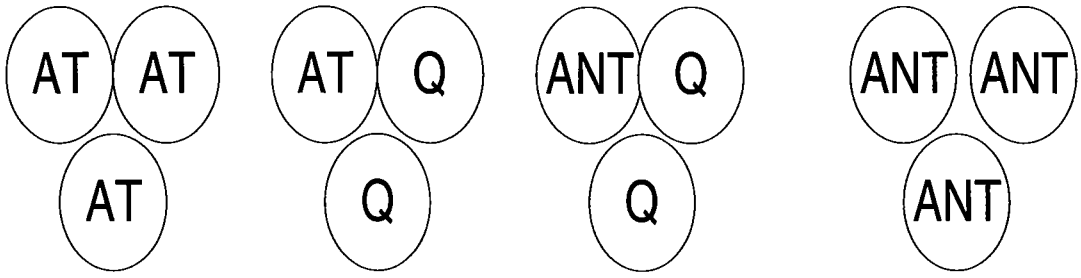

Figure 2.2. The four nest treatments used in trial 1. Each oval indicates an egg and a set of three indicates a nest treatment. The first letter indicates egg type (A= artificial wax egg, Q= quail egg). The subsequent letters indicate whether or not an egg is tied down (T= tied down, NT= not tied down), this only applies to wax eggs as quail eggs could not be tied down. From Left to Right = Treatments 1-4.

On the 10th June 2005 160 small piles of stones 15-25 cm in heights (cairns) (Figure 2.3) were constructed at approximately 25 m intervals, in four lines of 40 nests, creating a grid of nests 1 km long by 75 m wide. This cairn type is commonly used to identify nests in braided rivers (Crossland, pers comm.). The 25 m intervals are large enough to not be at the extreme minimum density of Banded Dotterel nests however most habitats do not support this density. The gull species in the river nest at higher densities but the other waders nest at lower densities. There were 40 of each nest treatment type and these were randomly allocated to a cairn. On the 13th June 2005 the artificial nests were set up. Approximately 1.5-2.5 m to the right of each cairn a small depression was created by taking a nearby rock with a rounded end and hitting the ground to produce a small hollow similar to those dug by Banded Dotterels. The eggs for the nest treatment allocated to that cairn were added to the depression in a triangular pattern (Figure 2.4). The wax eggs that were tied down were tied using monofilament nylon line (6.8 kg breaking strain). During this trial most of the wax eggs were tied usually to stones about =500 g, or occasionally to well-rooted vegetation if available. In the first treatment where three wax eggs were being tied into a nest they were all tied together.

The setup day was Monday 13th June (Day 0) and the nests were checked on a Monday, Wednesday and Friday schedule (Day 2, 4, 7, 9, 12....). Checking involved returning to each nest and, if upon a visual inspection it appeared the nest may have been interfered with, a thorough inspection of the eggs was conducted. Where interference was confirmed the wax eggs that could be recovered (=10min search of

the area) were collected. So many interference events occurred during the first two days that the 15th June nest inspections were completed on the morning of the 16th. Where it was evident that a nest had been disturbed but the wax eggs had little or no damage these were returned to the nest depression (reset nests). On the 17th June the 42 nests that had had their original wax eggs replaced and the 10 nests which had survived the first two days were inspected. This time the wax eggs were all collected in when interference was evident and no nests were reset.

Figure 2.3. Cairn used to mark nest locations. Scale object = Digital camera case, 13 cm long.

Figure 2.4. Example of an artificial nest setup from Trial 1. (Coin is 31mm diameter).

2.3.3 Trial 2

2.3.3.1 Development of the wax egg for Trial 2

This had the same setup as Trial 1, except labels were not included on the inside of the egg, instead only in permanent marker on the outside. Also the wax eggs were not weathered before being put into the field.

2.3.3.2 Trial 2 Experimental Setup

On the 24th June 18 new cairns and nests were set up approximately 2 km upstream of the first nests. This time one real egg was added to each nest depression. The nests alternated between quail eggs and chicken eggs, beginning with a quail egg, e.g. nest 1 = quail egg, nest 2 = chicken egg, nest 3 = quail, etc. Nests were checked on the

27th June and again on the 28th June, where all of the eggs had survived. A tied down wax egg was then added to each nest. Now each nest contained a real egg (quail or chicken) and a wax egg. The nests were checked again on the 30th June. Seventeen of the 18 nests had been interfered with and the wax eggs missing, so in addition to recording the failings where possible I determined the reason for the failure of the tie down.

2.3.4 Trial 3

2.3.4.1 Trial 3 Experimental Setup

On Wednesday 6th July, 16 cairns from trial 2 (cairn numbers 3-18) were reused, this time one real egg was added to each nest, alternating between quail and chicken eggs again. This time the eggs were left until something happened (i.e. wax eggs would not be added at any stage). The monitoring schedule was Monday, Wednesday, and Friday.

2.3.5 Trial 4

2.3.5.1 Development of the wax egg for Trial 4

This had the same setup as Trial 2, except no labels were used at all and instead of adding layers of dyed wax, the eggs were sealed with plain wax and then painted with a pale cream/green base (froth green, Karen Walker paints 7GO11) and speckling was mimicked with brown (brown derby, resene paints 2BO10) and black (nero, resene paints 1GR54). The base colour was painted with a paint brush and the speckles were created using a tooth brush (Figure 2.5).

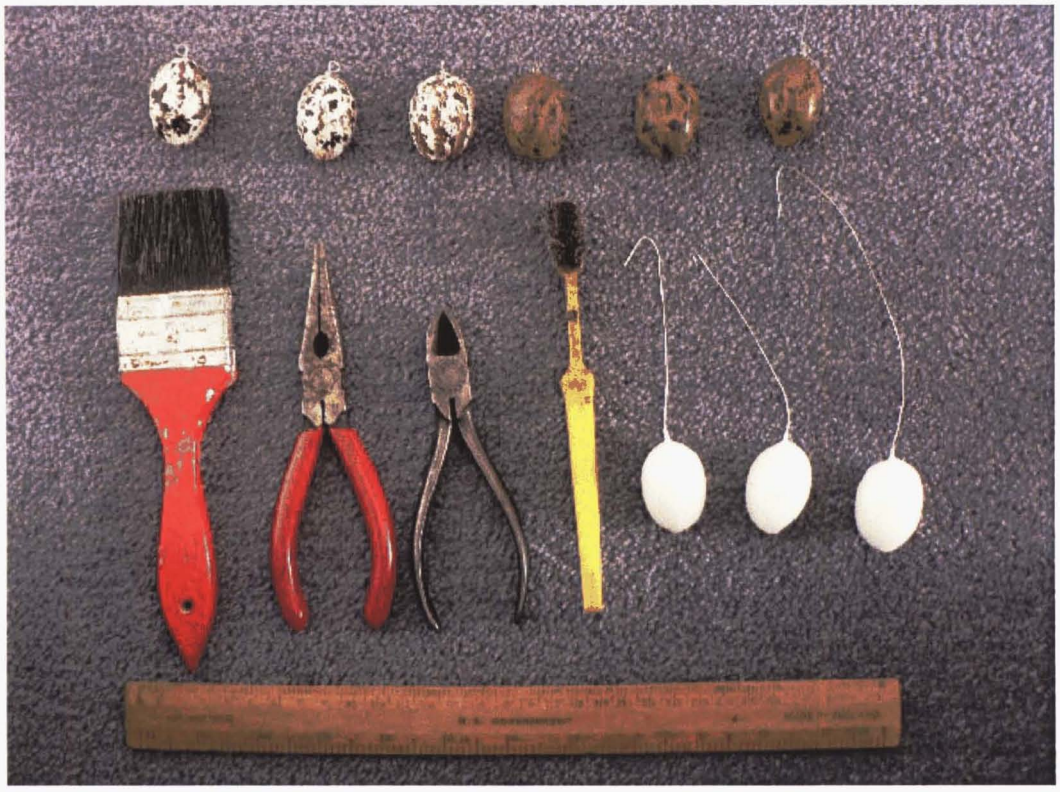

Figure 2.5. Example of the wax eggs and brushes used to paint them. Tin snips for cutting wire and long nosed pliers for making the loop at the base of the wax eggs.

2.3.5.2 Trial 4 Experimental Setup

On Monday the 8th of August 24 of the new painted wax eggs and 24 chicken eggs were put in artificial nests. For Trial 4 I returned to the original study site (used in Trial 1) and the 24 painted eggs were put singly at nest numbers 1-24 and the chicken eggs from 56-80. The painted wax eggs were tied down; however this time 22.7 kg strength line was used, also rocks were more carefully selected to reduce the risk of the tie line simply slipping off. Hindsight would suggest I should have randomly assigned these nests like Trial 1 to remove potential block effects.

2.4 Results and Discussion

In Trial 1, only 10 of the 160 nests survived the first two days. All 10 of these nests contained only wax eggs, six from treatment 1 and four from treatment 2. Of these 10

nests only two survived a further four days and both of these were from treatment 1. All wax eggs in nests containing quail eggs had been interfered with over the first two days with only one quail egg not being depredated. Some nests that had been interfered with, however, had suffered little damage to the wax eggs and 42 such nests were reset on day 3 and checked on day 7 along with the surviving nests. 34 of the nests which had been reset on day 3 were interfered with again. Another interesting observation on day 7 was the discovery of a wax egg from nest 147 in nest 150 which suggested that the predator transported the wax egg at least 75 m. Also the quail egg shells were usually found in or around the nest (within 2 m) and consistently appeared to have been struck on one side while on the ground. The damage to the wax eggs usually consisted of a few shallow (0-1.5 mm deep) U-shaped punctures. Shallow scratches (0-1 mm) were also common. One wax egg had definitely been chewed on and some of the wax had been peeled off. There were six nests where fresh avian scat was present.

The widespread interference of nests and the nature of the damage to the wax and quail eggs suggested avian predation. The small U shaped punctures were consistent with beak tips and not mammalian teeth. The way quail eggs were usually broken on one side was consistent with avian predation. Mammalian predators usually crush eggs from both sides in their teeth. It is likely that one avian species was responsible for the majority of interference event and possibly by one or very few individuals. The avian predator species present in the area are Southern Black-backed Gull (*Larus dominicanus* Lichenstein), Harrier Hawk (*Circus approximans* Peale) and Australian Magpie (*Gymnorhina tibicen* Latham). If mammals were responsible it is more likely to be few individuals following scent trails. Keedwell & Sanders (2002) found that it was unlikely predators following human scent trails caused increased predation in braided river areas as predation wasn't significantly different at visited and unvisited nests. Investigators visiting artificial ground nests baited with quail eggs were also found not to affect success or failure (Gottfried & Thompson, 1978). Based on this it is my opinion that it is unlikely that mammals, even if in very high numbers, would visit such a high proportion of nests in such a short time.

There were only three nests where neither the wax eggs nor the quail egg could be recovered. The total number of wax eggs that were lost from each treatment is as follows: Treatment 1 = 2, Treatment 2 = 21, Treatment 3 = 15, Treatment 4 = 11. The total wax eggs lost at nests where tie downs were used was 13 against 36 where the wax eggs were left untied. The results suggested that tying down the wax eggs would help these to be retained in the vicinity of the nest. The nature of the interference events also makes it difficult to infer anything about the need for quail eggs to induce predation. Both nests with and without quail eggs were interfered with.

Following Trial 1 it was clear that changes needed to be made to the methodology. The widespread interference observed in Trial 1 was unlikely to mimic the natural situation. Trial 1 resulted in the question 'what was it that the predators were cueing off in order to locate the nests so readily?' Possible reasons were: that unprotected real eggs (quail) could be spotted easily by avian predators, or perhaps the wax eggs were easily spotted and drew the predator in, resulting in them finding the quail egg, making a connection between the two and subsequently finding as many wax eggs as it could trying to find food (the quail eggs). Another possibility is that this was a random event that would be unlikely to occur again.

Trial 2 was an attempt to get an understanding of the cause of the widespread interference observed in Trial 1. Trial 2 used a site approximately 2 km upstream of Trial 1, 18 new cairns and artificial nests were constructed and each nest had one real egg added alternating between chicken and quail eggs. All real eggs survived for four days at which time a dyed wax egg was added to each nest. Within two days of the wax eggs being added 17 of the 18 nests had been interfered with. The real eggs had been broken and eaten and the wax eggs were missing. The wax eggs were lost for a variety of reasons (Table 2.1), and this is the one and only time that a mass loss of tied down eggs occurred.

Table 2.1. Overview of the reasons why the tethering of the wax eggs failed during Trial 2.

How the wax egg was lost	Proportion of nests n=17
Wire snapped	12%
Wire pulled out of the wax egg	24%
Failure in the fishing line tie down	29%
Unsure	35%

The failure of the fishing line tie down was addressed in future trials in two ways; where possible the wax eggs were tied off to vegetation instead of rocks and when rocks were used extra care was taken to select a suitable rock. The suitability of rocks depended on their weight (approx >500 g) and their shape, rocks with a 'neck' in them at a point where the fishing line would not slip or loosen. No changes were made to the wire because a heavier gauge wire would have made it difficult to make the loop at the base of the egg for the tie down.

The results of Trial 2 were insufficient to be confident about the reason for the widespread interference that was being observed. Interference did not happen until wax eggs were added to the nests. However, there was the possibility that predation events may have occurred even if I had not added the wax eggs. Trial 3 was intended to see how long quail eggs and chicken eggs would survive without wax eggs being added at any stage. In Trial 3 all 16 eggs were interfered with during the first two day monitoring period. The nature of the shell fragments left at the nests was again consistent with avian predation. At this point it seemed that the avian predators were potentially able to cue off either the wax egg or real egg.

At this stage the breeding season was drawing near and a significant improvement in the performance of the wax eggs was needed if they were to be added to Banded Dotterel nests. Instead of being dyed, the wax eggs were painted with a pale green base colour and speckled brown and black. This was to make them closer mimics of Banded Dotterel eggs and make them more cryptic against the riverbed background.

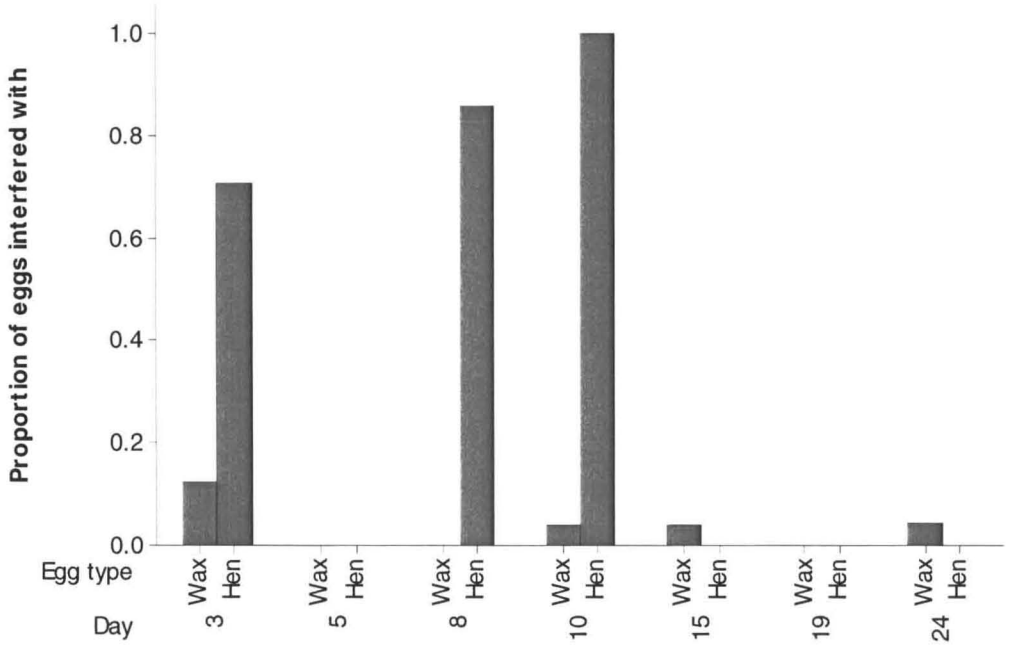

Figure 2.6. Proportion of each egg type found interfered with on each monitoring day during Trial 4. Starting N=24 (Day3), any subsequent day N=24-(proportion of eggs lost during earlier periods)

It appeared that the earlier type of dyed wax egg was inducing avian predation, so the goal of the painted wax egg was to better mimic real eggs and therefore reduce this rate of predation to something more similar to a natural predation rate. To test whether or not the painted wax eggs approximated a natural predation rate the interference of the painted wax eggs was compared to the interference of chicken eggs (Figure 2.6). The painted wax eggs were interfered with infrequently throughout the 24 day period whereas large proportions of the chicken eggs were interfered on days 3, 8 and 10. This interference indicates that the predators were still present in the area but that the painted wax eggs did not induce predation in the way that the dyed eggs had. Another key observation during trial 4 was that the interference event observed on day 24 could definitely be attributed to a mammalian predator (probably ferret (*Mustela furo L.*) based on the marks on the wax egg and foot prints in the area. Also of note was the fact that the animals' path was at an angle to the path I walked to monitor the nests and only one nest was disturbed. So it is unlikely the predator was following my scent trail, a concern expressed by Bart, 1977; Gotmark, 1992b; Wilson *et al.*, 1998.

Following the results of Trial 4 the painted wax eggs were used during the breeding season (Chapter 3:). Both the original painted eggs described above and also wax eggs painted with an olive green base described below were used. The two colours were used because the colour of Banded Dotterel eggs varies from pale to dark and it was thought that the original pale wax eggs were at the extreme pale end of the Banded Dotterel egg colour range.

The artificial eggs were reasonably simple to produce. With the nonspecialised setup I had, it would take approximately 15 mins work per painted wax egg and probably 5 mins for the dyed wax eggs. These times could be reduced dramatically with a more streamlined processing system. The entire amount of wax used in this series of studies cost $100 and, including all other materials, the overall cost was approximately $400-$500. The total number of wax eggs produced was around 700-750 meaning the value of materials in a wax egg could be as little as 55 cents.

The artificial wax eggs were made using a microcrystalline wax as it is less brittle than paraffin wax, is reasonably malleable at room temperature and has a low palatability (predators rarely consume the wax). As a result bite marks from predators are of high quality, usually allowing identification of species without the predator consuming the evidence (Thomas *et al.*, 2002a; Thomas, 2005a).

Thompson and Burhans (2004) used a short length of monofilament to tie their plasticine eggs to artificial nests, to deter predator removal. I used a similar technique, however, rather than being tied off to the nest, as there is a paucity of options to tie to in dotterel nests, I tied off to vegetation or rocks when suitable vegetation was unavailable. In general this appears to have worked well and it appeared sensible to adopt the practice during the breeding season (Chapter 3:). Minor changes were made to the line strength and tying method to try and prevent the egg loss that occurred in Trial 2. Subsequently wax eggs were not being lost, so the egg loss appears to be an isolated incident.

I used 22 gauge wire in my wax eggs. However, other strengths could be used, as there has to be a trade-off between the flexibility of the wire for its ease of use and the strength so that wax eggs are not taken by predators. In this study 22 gauge wire worked well and I would recommend its use again.

Paint generally does not bond well to the wax. The paints that I used, however, worked well, they bonded sufficiently when allowed to dry and did not wash off in the rain. I was initially advised that a sealer would be required if I was to paint wax, however, the sealer did not bond to the wax and simply drained off. The choice of paint is important because some paints will drain off before they dry. Once the wax eggs were painted they had to be handled with care and not allowed to heat up (e.g. in a hot car) as the paint can get sticky and come off. Gaps in the paint cover can cause problems with wax eggs in the direct sunlight for a long time (several weeks) (Chapter 3:). In some cases when predators interfered with the eggs much of the paint was stripped away. It appears that the paint sticks to itself rather better than it sticks to the wax. Painting the wax eggs had one major benefit over dying and that was the ability to choose your colour and have it consistent. Dying the wax required mixing wax dye blocks into molten microcrystalline wax and it is very much a trial and error process to get the desired colour.

2.5 Summary

It seems the importance of the artificial egg colour or type varies depending on the individual circumstances of the nest predation study. It is presumed that a major function of egg colour is protection from visually oriented predators (Wilson *et al.*, 1998). Yahner & Mahan (1996) conclude that 'colour rather than egg size was the major factor influencing nest disturbance in our study'. However, Major & Kendal (1996) provide examples of studies which found egg colour did not influence predation. Also Mezquida & Marone (2003) argue that recent studies show that colour is not an important consideration. These conclusions are at odds with my

results which suggest that colour may have a lot to do with the predation observed at my artificial nests, both prior to (Chapter 2:) and during (Chapter 3:) the breeding season. The avian predators suspected to be responsible for the bulk of the predator throughout these trials are 'visual' predators. So an understanding of their perception of colour is important when using an interference device to monitor predation. Although the optical properties of the avian predators involved in this study, Southern Black-backed Gull, Harrier Hawk and Australian Magpie, have not been tested some related species have. Species in the *Larus* genus were found to have ultraviolet biased vision, whereas a *Circus* species, Marsh Harrier (*Circus aeruginosus L.*), has violet biased vision (Odeen & Hastad, 2003). So the potentially differing visual spectrums between the potential predator species may influence their reaction to interference devices presented to them.

The results suggest that the use of real eggs (chicken or quail) in artificial nest studies on braided river systems may be inappropriate. The high predation rates observed when real eggs were used mean that they would not provide an accurate indication of predation at real nests. In addition it is likely that little important information could be gained from relative rates of predation on artificial nests baited with real eggs.

High predation rates observed using dyed eggs and real eggs when compared with the much lower predation rates obtained using cryptically-painted eggs suggest that a significant contributing factor to high predation at artificial nests may be the high contrast between the eggs in the nest and the surrounding environment. However, a study looking at the effect of different egg types, colours and contrasts on predation is required to confirm this theory.

Wax eggs are easy to produce, only one person is required and all necessary materials and equipment are readily accessible. The material cost of each painted wax egg was approximately 55 cents. This is important as a driving force behind using wax eggs on braided rivers is the need for a cheap monitoring tool so that you do not have to worry if they are lost or destroyed by flooding, vehicles or vandalism.

With the results gained from this process of refining and trialling the wax egg methodology led to the conclusion that I would able to trial the use cryptically painted wax eggs in Banded Dotterel nests. Critically, I was now confident that the painted wax eggs would be unlikely to greatly increase the predation risk at real nests. The following chapter compares the use of cryptically painted wax eggs in artificial nests with wax eggs in real Banded Dotterel nests.

Chapter 3: Comparing Artificial Nests with Real Nests

3.1 Abstract

Studies involving artificial nests often use an inappropriate context, sometimes conducted outside the main breeding period, or poor imitation of natural nest site selection, often in the past inference about real nest predation has been made without verification or calibration. Conclusions are often drawn along the lines that the relative rates of predation, patterns of predation and predator suites differ between artificial and real nests. I examined the potential of wax eggs as a means to measure interference, and whether predation on artificial nests accurately reflects that of real nests of Banded Dotterel in the Waimakariri River, New Zealand. I monitored 58 real nests and 52 artificial nests in two areas, using two wax egg types to record and identify predators. Wax eggs were accepted by the majority of incubating adults and were seldom left unmarked following a predation event. Impressions in the wax usually only enabled predation to be assigned to a predator group rather than species. Impressions could usually be identified as being avian or mammalian and were identified to species level in 7 occasions, 2 Black-backed Gulls and 5 Hedgehogs. For real nests, the level of avian predation was almost twice as high as that for mammalian predation. Variation in nest predation levels in relation to nest location and wax egg type was similar in artificial and real nests. However, mammalian predators were underrepresented at artificial nests and avian predators overrepresented. It is possible that the observed difference between historical Banded Dotterel predation results and this study may be due to avoidance of avian predators to the presence of nest monitoring cameras. The two main potential avian predators, the Harrier Hawk and Southern Black-Backed Gull probably use different visual cues and an understanding of how each species responds to the wax eggs may be required before the technique could be used on a large scale. These are important considerations in the development of an artificial interference device technique. These results suggest that careful consideration should be given to the applicability of

artificial nests in each unique situation. At the very least, in studies involving a target experimental species, the results from artificial nests must be verified/calibrated with real nests. However the use of artificial nests may be appropriate and should not be discounted in situations where the identification of predator presence is the objective. In particular situations where a species is highly endangered and therefore real nests simply are not available.

3.2 Introduction

Artificial nest experiments have been commonly used in an attempt to understand patterns of predation affecting real nests (Storaas, 1988; Willebrand & Marcstrom, 1988; Major & Kendal, 1996; Wilson *et al.*, 1998; Bayne & Hobson, 1999; King *et al.*, 1999; Burke *et al.*, 2004). Using artificial nests is usually easier and more time efficient than studying real nests. Artificial nests are usually also more suitable for experimental manipulation. Initially there was little recognition of the potential problems associated with the use of artificial nests. However, a growing body of literature suggests that neither relative rates nor patterns of predation are necessarily the same for artificial and real nests (Burke *et al.*, 2004). Artificial nest studies that compared the artificial nests with real nests have found both higher (King *et al.*, 1999; Berry & Lill, 2003; Mezquida & Marone, 2003; Burke *et al.*, 2004), lower (Davison & Bollinger, 2000; Robel *et al.*, 2003) and similar (Buler & Hamilton, 2000; Part & Wretenberg, 2002; Thompson & Burhans, 2004) predation rates. It has been suggested that conclusions about real nests derived from artificial nest studies may be unfounded and should be avoided (Wilson *et al.*, 1998; Zanette, 2002; Robel *et al.*, 2003; Burke *et al.*, 2004).

A primary reason for differences between predation rates of real and artificial nests may be that they attract different predators (Haegen *et al.*, 2002; Moore & Robinson, 2004; Thompson & Burhans, 2004), therefore, caution should be exercised in making management decisions based upon results of artificial nest experiments (Ortega *et al.*, 1998). Artificial nests may only predict the risk for real nests when the nest predator

species are similar among the two types of nest (Part & Wretenberg, 2002). The absence of adult birds has been suggested as a cause of lower predation at artificial nests as predators may cue off adult birds to locate nests (Willebrand & Marcstrom, 1988; Villard & Part, 2004) although adults may also deter predators as well. In most studies that do address variation in predator response to nest type, snakes are a major predator of real nests but are seldom represented in artificial nests (Davison & Bollinger, 2000; Thompson & Burhans, 2004). The under representation of snakes may be a result of a lack of visual cues given by intense parental mobbing behaviour at real nests (Davison & Bollinger, 2000). It may be that snakes require a combination of visual and chemical stimuli to respond to nests. It appears that the cold relatively scent free, unattended eggs in artificial nests do not stimulate snakes to eat them (Davison & Bollinger, 2000). The lack of snakes in the New Zealand environment may mean techniques invalidated due to snakes in other areas may work in New Zealand. However, alternatively the lack of parental defence, coupled with greater conspicuousness of artificial nests, has also been suggested as contributing to higher predation at artificial nests (King *et al.*, 1999).

Burke *et al.*, (2004) contend that the considerable time and effort spent creating artificial nests and eggs that resemble real nests should be spent searching for and monitoring real nests. These authors also assert that the applicability and reliability of results from real nests cannot be questioned. However, this belief is not universally held and the difficulties mentioned above do not mean that we should discount artificial nest methods. The monitoring techniques used at real nests may, themselves, bias observations. These biases can be summarised in two main points: (1) nests detected by observers may be slightly more exposed than the average nest in the breeding population and (2) in spite of precautions followed by researchers, regular visits to monitor nest fate may increase the probability of failure by creating a trail for both visual and olfactory-searching nest predators (Villard & Part, 2004), i.e. a subgroup of potential predators. Whelan *et* al., (1994) concluded that olfactory-searching predators can cue on human odours left in the area of artificial nests, but that either rain or scents (e.g. deer scent) can be used to decrease this potential bias. More recently Keedwell & Sanders (2002) found that it was unlikely predators following human scent trails caused increased predation in braided river areas as

predation was not significantly different at visited and unvisited nests. Finally, It is time-consuming and difficult to find real nests, which are seldom distributed across treatments in sufficient numbers for powerful statistical analyses (Moore & Robinson, 2004).

Artificial nest experiments may, under certain controlled conditions, represent a useful approach to address conservation questions; and the development of reliable indirect approaches in general should be encouraged rather than condemned (Villard & Part, 2004). Villard & Part (2004) agree that a healthy dose of skepticism is required when evaluating studies in which artificial nests have been used to estimate relative reproductive success, but also believe that we should not 'throw the baby out with the bathwater'. Studies comparing real and artificial nests that are cited to reject the use of artificial nests are not without biases (Villard & Part, 2004). In most of these studies, the realism of the mimics could be questioned. In others, artificial and real nests were spatially separated or experiments were conducted with real nests but after the main breeding season, when predator search images may have changed. Still others have used relatively exposed artificial open-cup nests without attempting to camouflage the eggs, and this may attract different predators than real nests (Villard & Part, 2004).

Studies often conclude that artificial nests and eggs should mimic those of the target species as closely as possible. This is because unrealistic artificial nests and eggs may result in patterns of predation that do not accurately reflect those of real nests (Davison & Bollinger, 2000; Berry & Lill, 2003; Mezquida & Marone, 2003; Villard & Part, 2004). Changes in procedures for artificial-nest studies that reduce spatially and temporally clumped predation and prevent the exclusion of small-mouthed predators could increase the suitability of such studies as a model for predation at real nests (Buler & Hamilton, 2000).

Studies have suggested that although artificial nests should not be used to measure actual rates of nest predation or parasitism, they may be valuable for detecting trends in rates of predation (Wilson *et al.*, 1998) and may provide an additional source of

data to real nests when testing ecological hypotheses (Mezquida & Marone, 2003). Wilson *et al.,* (1998) recommend using artificial nests primarily in pilot studies or in conjunction with active nests, because of the many potential biases associated with the use of artificial nests. Mezquida & Marone (2003) and Weidinger (2001b) suggest that you should attempt to identify predators of artificial and real nests to validate the experimental results. Villard & Part (2004) advise that such validation is needed to justify artificial nest experiments. This has rarely been done and might be impossible for some focal species (Willebrand & Marcstrom, 1988; Villard & Part, 2004). It is necessary to determine whether indirect methods provide good relative measures of reproductive success in each study, irrespective of the fact that the method has been calibrated in another system (Villard & Part, 2004).

The vast majority of artificial nest studies and review articles deal with either the ability of artificial nest experiments to detect trends or the reliability comparisons between artificial nests and real nests. A rarely explored alternative is the use of artificial nests simply as a tool to detect the presence of predator species. In this situation it may not be necessary to make elaborate mimics of real nests and eggs. Simply because you are interested in what predators are in the area and not what is happening for a particular species. Wax eggs have potential as interference devices to indicate the presence of and identify the predator 'guild' and, in some cases, species. When presence and identity of predators is your goal without any specific prey species, comparisons involving wax eggs could be used in a 'nest-like' set up and placed throughout the habitat. The issue of whether or not all predators present in an area will interfere with the wax egg still exists. However, this is less restrictive than the need for all predators of real nests to be represented in similar proportions at artificial nests. The need for an accurate mimic is negated as you are not attempting to mimic anything in particular. Many of the problems outlined earlier are specific to the use of artificial nests and eggs to indicate nest success of a target species. The majority of criticisms of artificial nests are negated by using them as a tool to detect the presence of predator species in much the same way as tracking tunnels are used to detect the presence of mammalian predators.

Species nesting in braided rivers are at threat from introduced predators and changes in vegetation (Pierce, 1986; Rebergen *et al.*, 1998; Sanders & Maloney, 2002). Sanders & Maloney (2002) quantified the impact of predators in the Upper Waitaki Basin of the South Island, New Zealand using video cameras at nests. They implicated, in decreasing importance, Cats (*Felis cattus L.),* Ferrets, Hedgehogs (*Erinaceus europaeus L.*), Stoats (*Mustela erminea L.*), Harriers and Magpies. In addition to these Norway rats (*Rattus norvegicus* Berkenhout, 1769) and Black-Backed Gulls are suspected to contribute (Pierce, 1986; Rebergen *et al.*, 1998). It is likely that the impact of these species varies spatially and possibly temporally through the breeding season. For example if a braided river was bounded by large amounts of tall vegetation then the stoat population may be at a higher density than ferrets and they may have a greater impact on riverbed nesting birds. Also Black-Backed Gull nest predation may be concentrated in areas adjacent to colonies where these gulls are nesting.

In this study, we examined whether predation on artificial nests reflects that of Banded Dotterel nests in the Waimakariri River, eastern South Island of New Zealand. We compare survival rates for real and artificial nests in two study areas, 'baited' with either a cream or green wax egg in order to identify predator group or species where possible. The implications of the results on the use of artificial nests and wax eggs as monitoring tools are discussed.

3.2.1 Objectives

- Are survival rates of artificial nests baited with wax eggs equal to those of real Banded Dotterel nests baited with wax eggs?
- Is the predator suite the same between artificial and real nests?
- Does the colour of the wax egg effect the survival rate or predator species?
- Does survival rate differ between the high disturbance (recreational and industrial) area (Location 1) and low disturbance (Location 2)?

3.3 Methods

3.3.1 Study Site

The study area was the riverbed of the Lower Waimakariri River, upstream from the State Highway 1 Bridge where the braided river type begins. The condition of the riverbed in this area is very good with multiple braids and a range of micro-habitats suiting the requirements of most riverbed species. Vegetation encroachment has been observed to be far less widespread than on many other lowland rivers (Waipara, Ashley, Selwyn, Ashburton, Hinds, Opihi, Orari and Waitaki) (Crossland, pers comm.). Two distinct study areas were used, these locations are referred to as Location 1 and Location 2 (Figure 3.1). Several factors contributed to the use of these areas. The primary factor was the relatively high Banded Dotterel nest density in these two areas. Secondly they represent two different areas with respect to management, Location 1 = high disturbance (gravel extraction/recreational use), Location 2 = low disturbance (no gravel extraction/low recreational use). Thirdly the abundance of southern black-backed gull differed (Location 2>Location1). Finally consistency of access was an issue, braided river channels and flows vary and the ability to consistently return to nests was important. These two locations enable an initial look at the variability of predation pressure within the Waimakariri River and the impact of human disturbance.

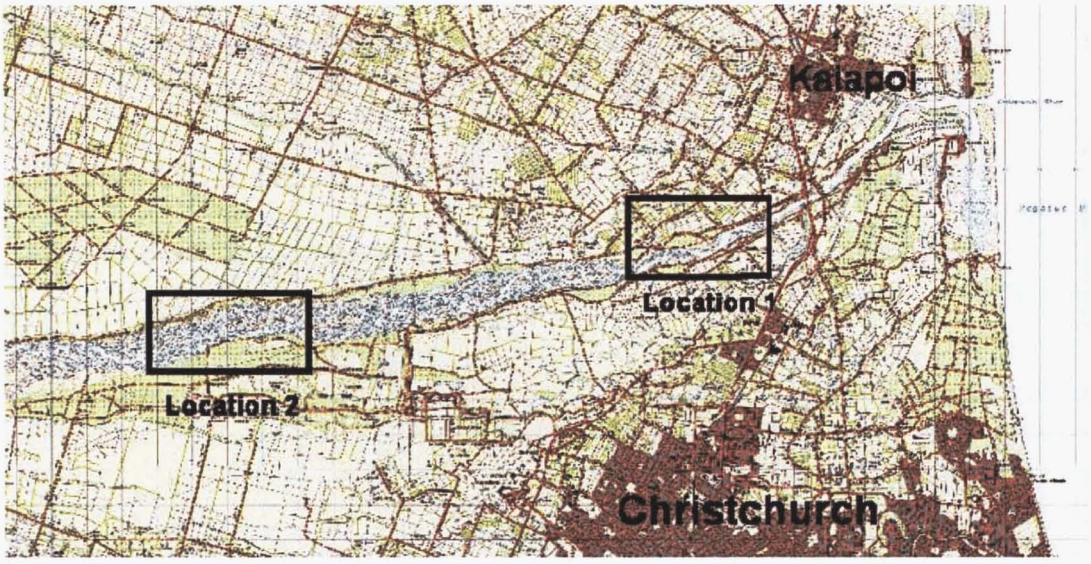

Figure 3.1. Location of study areas. The nests used in this study were clustered in two locations (hereafter referred to as Location 1 and Location 2).

3.3.2 Making of the wax egg

The wax egg was made in the same way as those used in Trial 4 (Section 2.3.5.1). However, because Banded Dotterel eggs can vary from pale green to deep olive green two different base colours were used, the pale cream/green base (froth green, Karen Walker paints 7GO11) here after referred to as 'Cream' and also an olive green base (Himalaya, Resene paints 1YO20) here after referred to as 'Green'. The speckling was again mimicked with brown (brown derby, Resene paints 2BO10) and black (nero, Resene paints 1GR54). Examples of the finished product can be seen in (Figure 3.2). The two wax egg colours are tested because preliminary trials had suggested that the colour of the wax egg may affect predation rates. Secondary to that is the fact that Banded Dotterel eggs vary in colour and the use of two colours mimicked that variation.

Figure 3.2. Examples of the cream and green wax eggs used during the breeding season.

3.3.3 Experimental Setup

Fifty-eight Banded Dotterel nests were located and monitored between 31 August 2005 and 23 December 2005 (Figure 3.5). The nests were cryptic and were located by observing the incubating adult bird. When disturbed the incubating adult moved quickly away from the nest at a roughly perpendicular angle to the observer's approach. Immediately after disturbance the observer retreated to reduce the apparent threat to the adult. The adult was observed as it returned to the nest and its location in relation to the features on the riverbed identified. On location of a nest a GPS coordinate would be determined and a cairn was built (Figure 2.3) approximately 1.5 m to the true left of the nest, in order to allow relocation of the nest. The wax eggs were tied using monofilament nylon to a nearby anchor of either rock or vegetation (<1.5 m from nest). The wax egg was then added to the Banded Dotterels' clutch which usually involved some slight manipulation of the nest (Figure 3.3). Banded Dotterel nests often contained small pebbles which could be removed to provide space for the wax egg. Sometimes the nest was slightly expanded by pressing a thumb into the side to create the extra space needed. In a couple of rare instances slight movement of the eggs was required. The main focus was to get the wax egg in low

enough that the incubating adult could comfortably sit on the entire clutch including the wax egg. The adult would then be observed returning to the nest.

Figure 3.3. Example of a Banded Dotterel nest with a wax egg added.

Occasionally, on return to nest sites, it was found that the wax egg had been removed, presumably by the adult birds (as this was observed on several occasions). In this situation the wax egg was added to the clutch again. This procedure was repeated as many times as required. Wax eggs were only added when it was deemed that the clutch was complete or nearly complete. Two real eggs in a nest were used as the criteria for adding a wax egg. This resulted in only 55 Banded Dotterel nests having wax eggs added. 32 cream eggs were used and 23 green eggs. Nests were usually checked every 2-3 days, although, monitoring intervals at some nests were up to 10 days because of high river flows. The three nests which did not have a wax egg added were left out of all analyses.

Groups of artificial nests were set up at various times throughout the Banded Dotterel nesting season. Artificial nests consisted of a small depression in the ground and two painted wax eggs of the same base colour (Figure 3.4). Lines or grids of artificial nests were set out in habitat suitable for Banded Dotterel nests. There were 25 m spaces between artificial nests. Sixty artificial nests were set out, 52 of those were set out in grids/lines of alternating wax egg colour (i.e. green cream green cream etc). The eight nests which were in grids/lines of a single wax egg colour were removed from the analysis. Artificial nests were checked in the same manner as the real nests. Although the artificial nests were monitored right through till 23 December 2005 resulting in some nests being over 100 days old, 30 days was used as a cut-off indicating nest survival (as this covered the maximum likely length of a natural incubation and it appeared that after approximately 30 days artificial nests were unlikely to be interfered with). Some wax eggs which had been in artificial nests for several weeks suffered in the heat of November, with some becoming sticky and air bubbles forming on the surface. These eggs were removed from the study area on 14 November and 21 November 2005. The age of eggs that were removed ranged from 31 days to 59 days and, therefore, did not affect the analysis.

Figure 3.4. Example of an artificial nest. Scale object = Garmin eTrex Handheld GPS unit 11cm by 5cm.

An artificial nest was considered preyed upon if any marks had been made on the wax egg, which is a procedure widely used in nest experiments (Reitsma *et al.*, 1990; Bayne *et al.*, 1997; Part & Wretenberg, 2002). The same criteria was used for real nests, except that 'sign at nest' was also used and in one case the damage to the wax egg was known to have been caused after chicks had hatched and so was not recorded as a nest failure. In another nest the wax egg was intact although the sign at the nest indicated predation. This nest was considered to have been preyed on.

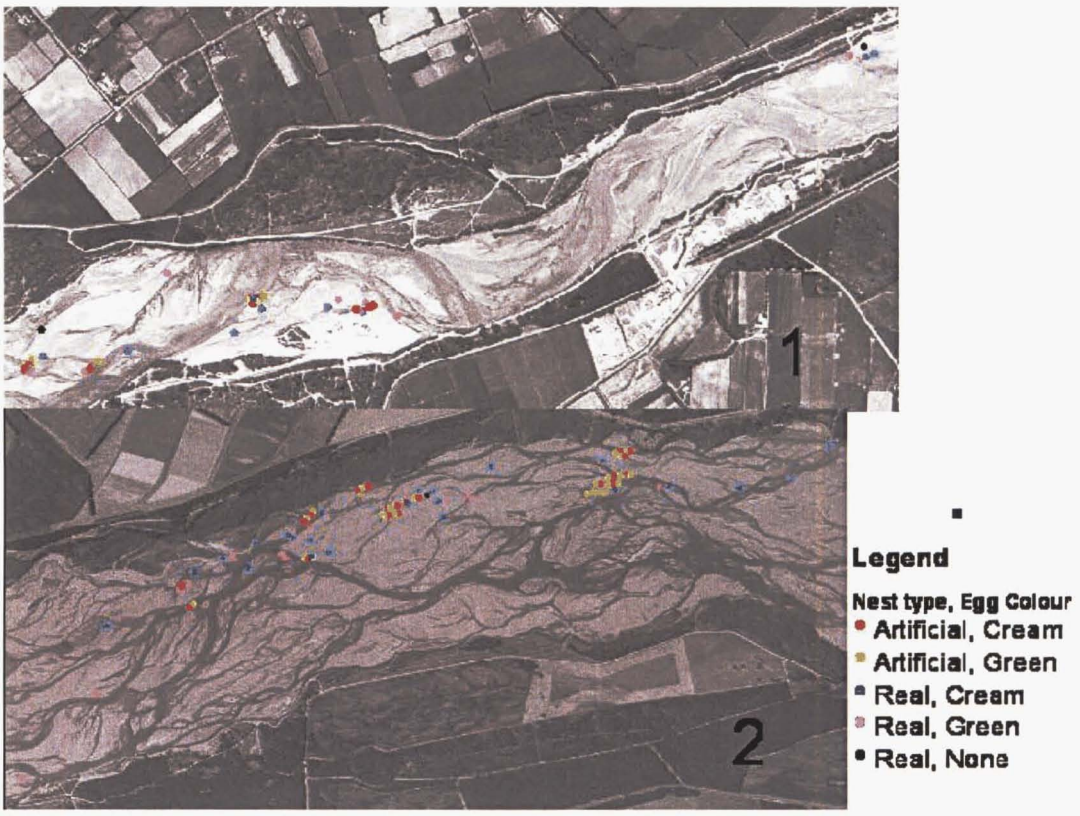

Figure 3.5. Real Banded Dotterel nests and artificial nest locations between 31 August and 23 December 2005. Bold numbers indicate location. The background aerial photo (2003) only approximates the location of current channels as they are constantly changing.

3.3.4 Analyses

A logistic-exposure model, $S_{\text{nest type+nest location+wax egg colour}}$, using PROC GENMOD in SAS 8 (SAS Institute 1999), a binomial response distribution, and the link function defined by Shaffer (2004) was calculated. The levels of the variables in this model were, nest type (real nests vs artificial nests), nest location (location1 vs location2) and wax egg colour (green vs cream). This model showed no significant effect for nest type and significant effects for nest location and wax egg colour. Then we decided to run separate models for the two nest types to see if the significant effects of nest location and wax egg colour remained within the nest types. Initially the models run were $S_{\text{nest location+wax egg colour+nestlocation*wax egg colour}}$. However the nest location*wax egg colour interaction was not significant in both the model for real nests and artificial nests and only the results for models $S_{\text{nest location+wax egg colour}}$ are presented

The parameter estimates from these model were used to obtain estimates of the link function for each level of the factors. The estimates were back-transformed from the logit scale to obtain predicted daily survival rate for each main affect level using (proportion = $e_{\text{estimate}}/[1 + e_{\text{estimate}}]$). The confidence intervals of daily nest survival were calculated using SAS least squares means and should only be regarded as approximate as a different method would likely give different confidence intervals. Daily survival rates were raised to the power of 28 to get the probability of surviving the approximately 28 day nesting period of Banded Dotterel.

Mayfield estimates were calculated for the two wax egg colour types and the overall survival rate from the 'real nest' data (Mayfield, 1961; Mayfield, 1975). I followed the Midpoint A method of Manolis *et al.*, (2000), except that when the hatching date was known for a successful nest that date was used rather than the midpoint. Hatching date was known when a nest was observed with both chicks and eggs in the nest.

Within the 'artificial nests' the proportion which survived 28 days (apparent nest success) and the confidence interval for the proportion were calculated. The 'artificial nests' were split by wax egg colour type and their proportions and confidence intervals were calculated.

The two methods were used in order to provide comparability between these results with historical and future data and also to provide an example of a comparison of the two techniques.

3.4 Results

Of the 58 Banded Dotterel nests located, 28 (48%) failed (26 due to predation, one to flooding and one to abandonment), 29 (50%) hatched and one had an unknown fate (Figure 3.6). For 24 of the 26 predation events there was visible damage to the artificial wax egg. One predation event occurred during the initiation of the nest, hence no wax egg had been added at that stage. Only one predation event occurred without any damage to the wax egg.

On five occasions the artificial wax egg was interfered with by a predator although all eggs in the nest survived and the adults continued incubating. At one nest a hedgehog predation event occurred and only the wax egg remained. The adult continued incubating the artificial wax egg and defended and displayed vigorously as the wax egg was removed.

The total number of interference events on wax eggs at real nests was 32 (including abandonment of nest which was not strictly wax egg interference). The reason for the interference was confidently identified in 73% of cases (45% avian (species unknown), 16% Hedgehogs, 6% Black-Backed Gulls, 3% flooding, 3% abandonment). The remaining 27% was attributed to the following: 10% possible mammal, 6% possible avian, 6% possible ferret and 6% unknown.

Twenty-seven (84%) of the 32 interference events above resulted in failure of the Banded Dotterel nest. For these nests the reason for nest failure could be confidently identified in 78% of cases (51% avian (species unknown), 15% Hedgehogs, 4% Black-Backed Gulls, 4% flooding, 4% abandonment). The remaining 22% was attributed to the following: 7% possible ferret, 7% possible mammal, 4% possible avian and 4% unknown (Figure 3.7). When broken down into coarse predator groups, 59% of the nests were attributed to avian predators, 29% mammalian predators, 4% flooding, 4% unknown and 4% abandonment.

The total number of interference events on wax eggs at artificial nests was 31 (total artificial nests n=52). The reason for the interference was confidently identified in 78% of cases (68% avian (species unknown), 10% run over by vehicle). The remaining 22% was attributed to the following: 13% possible avian, 6% possible mammal and 3% unknown (Figure 3.7). When broken down into coarse predator groups, 81% of interference events were attributed to avian predators, 6% mammalian predators, 10% were run over by vehicles and 3% unknown.

Introduction of wax eggs to Banded Dotterel nests were successful on the first attempt at 44 (80%) nests. With one, two, three and five 'reintroductions' of the wax egg needed at, 5 (9%), 4 (7%), 1 (2%), 1 (2%) nests respectively. Of the nests which required reintroduction 7 (22% of cream egg nests) were cream eggs and 4 (17% of green egg nests) were green eggs. The reintroductions were required because some incubating adults would remove the wax egg from the nest. This was almost always done by clasping the wire loop at the base of the wax egg in the beak and dragging the egg away.

Critical to understanding the differences in predation rates shown below is a breakdown of the type of predators depredating real and artificial nests (Table 3.1). Only one predation event at an artificial nest was attributed to mammals (4%) and 24 to avian predators (96%). Just considering the avian predation events at artificial nests, 19 (70% of all green egg nests) events were recorded on green egg nests and 5

(20% of all cream egg nests) at cream egg nests. However within the real nests the patterns were different. The avian: mammal split for real nests was avian 17 (65%) and mammal 9 (35%) (Table 3.1). At real nests avian predators depredated 31% of all cream egg nests and 30% of all green egg nests. It is important to note again at this point that the artificial nests were limited to a survival period of 30 days. Only 18 nests used in the analyses were monitored for a period longer than 30 days. Fourteen of these were cream egg nests and four were green egg nests. If the full periods had been used to calculate survival then the difference between cream and green eggs in artificial nests would have been even higher. However this would have been a rather meaningless result to compare between artificial and real nests.

Table 3.1. Number of wax eggs interfered with categorised by wax egg colour, predator type and nest type. In parentheses is the number of wax eggs interfered with as a percentage of those available in that wax egg colour and nest type.

Real Nests				Artificial Nests			
Avian		Mammal		Avian		Mammal	
Cream	Green	Cream	Green	Cream	Green	Cream	Green
10(31%)	7(30%)	5(16%)	4(17%)	5(20%)	19(70%)	1(4%)	0

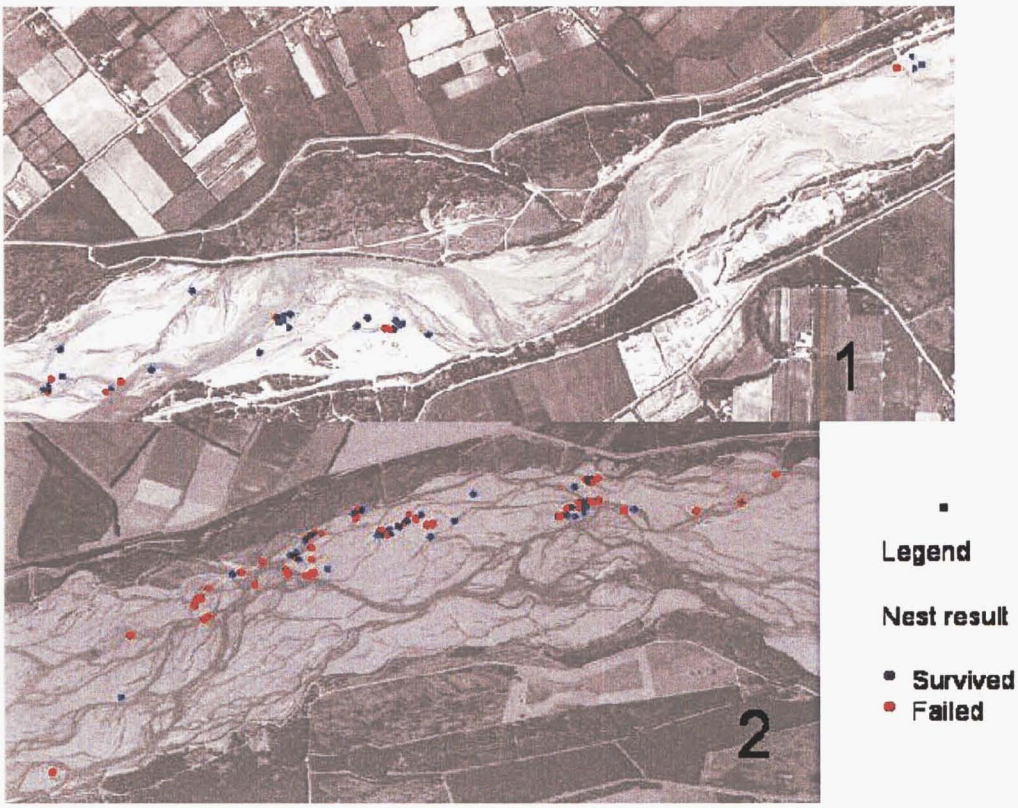

Figure 3.6. Distribution of nest successes and failures between 31 August and 23 December 2005. Real and artificial nests have been grouped together. Bold numbers indicate location.

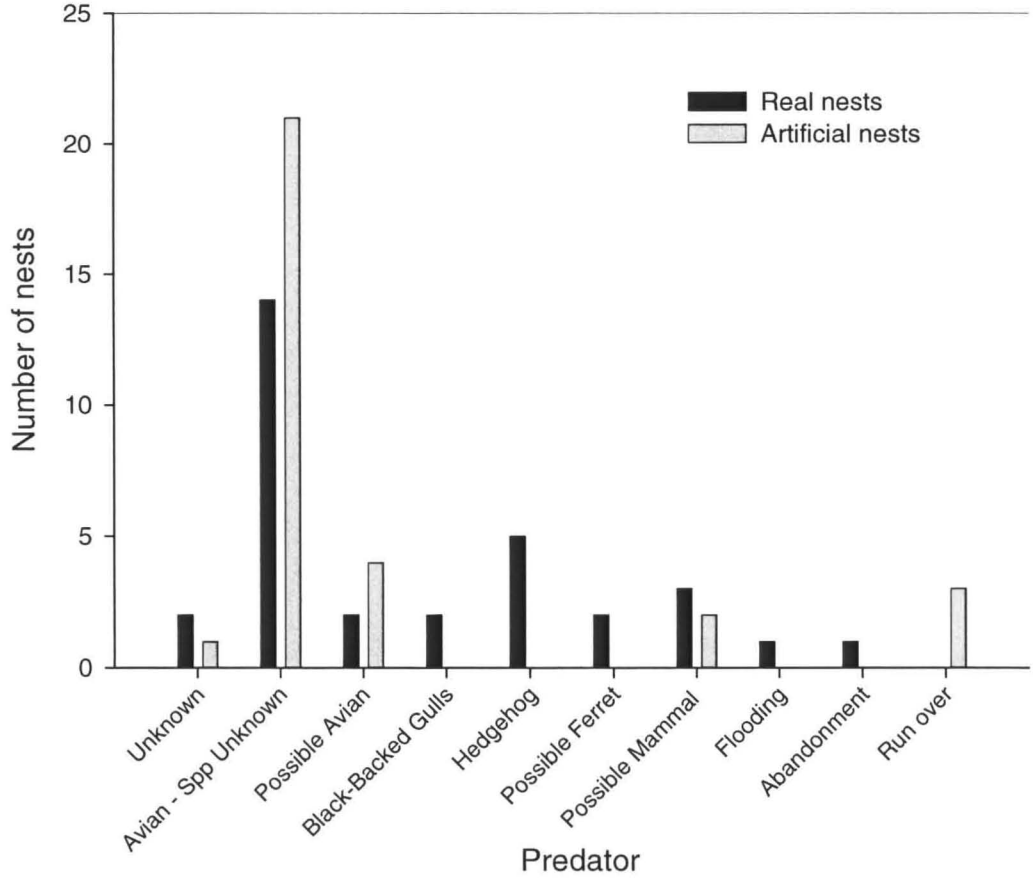

Figure 3.7. All causes of wax egg interference at real and artificial nests.

3.4.1 Logistic Exposure Model

3.4.1.1 Artificial vs Real nests

The logistic exposure model $S_{\text{nest type+nest location+wax egg colour}}$ showed that there was no significant difference ($P = 0.1661$) between the daily nest survival of real (0.974, N = 55, 95% CL 0.96 - 0.98) and artificial nests (0.982, N = 52, 95% CL 0.97 - 0.99). Based on these daily nest survival rates, nest survival for real nests and artificial nests was 48% and 60%, respectively.

3.4.1.2 Wax Egg Colour and Nest Location

Both wax egg colour and nest location were significant predictors of nest survival. The daily survival rate of cream wax egg nests was significantly higher than green wax egg nests in both real nests ($P = 0.018$) and artificial nests ($P = <0.001$) (Table 3.2, Table 3.3, Figure 3.8). The daily survival rate of nests at location 1 was significantly higher than location 2 for both real nests ($P = 0.004$) and artificial nests ($P = 0.011$) (Table 3.2, Table 3.3, Figure 3.9).

Table 3.2. Daily survival rate and 95% CIs, probability of surviving 28 days, and 95% CIs, and the *P values* for the difference between the two colours and the two locations, for results from real Banded Dotterel nests.

Main Effect Means							
	Daily survival rate, s	**95% Conf Interval**		**prob(surv 28 days), = s**28**	**95% Conf Interval**		**Pr> ChiSq**
Colour		**Lower**	**Upper**		**Lower**	**Upper**	
Green	0.958	0.92	0.98	0.30	0.11	0.53	**0.0189**
Cream	0.983	0.97	0.99	0.62	0.39	0.79	
Location							
1	0.988	0.97	1.00	0.71	0.40	0.88	**0.0045**
2	0.944	0.92	0.96	0.20	0.09	0.34	

Table 3.3. Daily survival rate and 95% CIs, probability of surviving 28 days and 95% CIs, and the *P values* for the difference between the two colours and the two locations, for results from artificial nests.

Main Effect Means							
	Daily survival rate, s	**95% Conf Interval**		**prob(surv 28 days), = s**28**	**95% Conf Interval**		**Pr> ChiSq**
Colour		**Lower**	**Upper**		**Lower**	**Upper**	
Green	0.963	0.93	0.98	0.34	0.14	0.57	**0.0001**
Cream	0.992	0.98	1.00	0.81	0.60	0.91	
Location							
1	0.992	0.98	1.00†	0.80	0.49	1.00†	**0.0117**
2	0.964	0.95	1.00†	0.36	0.21	1.00†	

† these values have been restricted to a maximum of 1 (100% survival) where the logistic exposure model resulted in values >1.

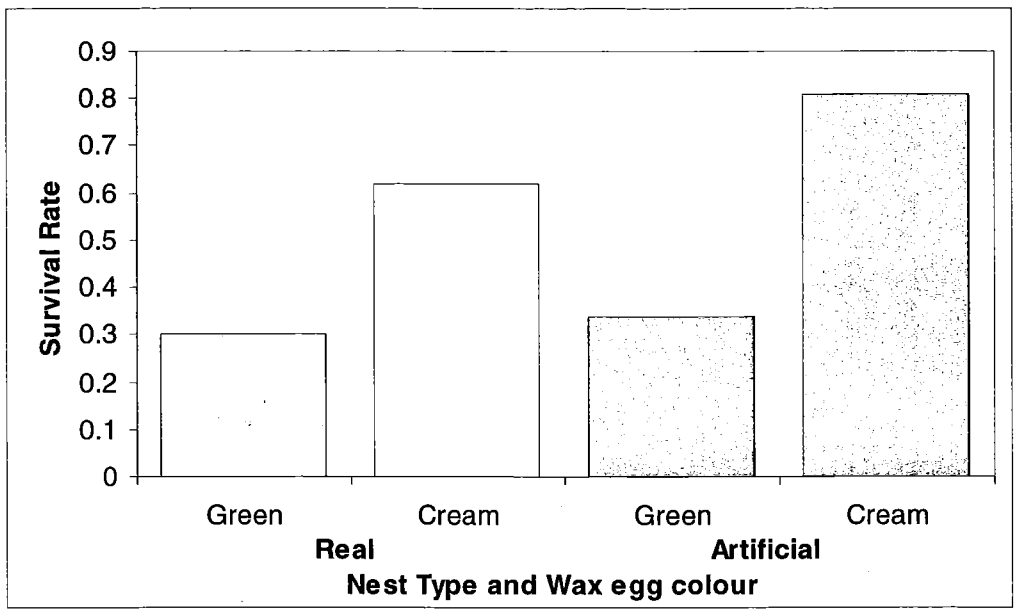

Figure 3.8. Probability of nests surviving 28 days, by wax egg colour (Green vs Cream) and nest type (Real vs Artificial).

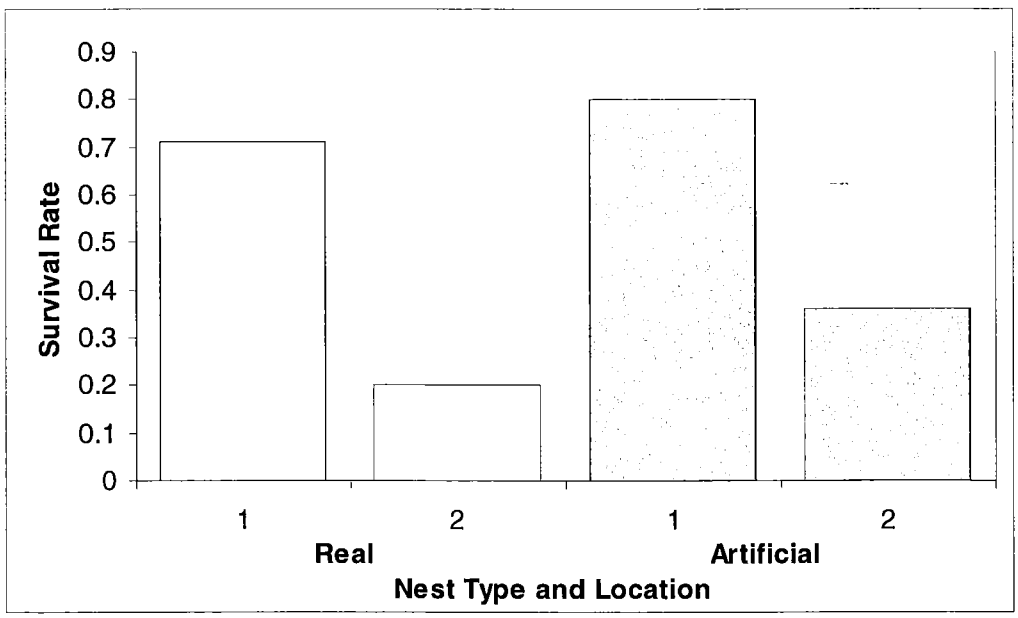

Figure 3.9. Probability of nests surviving 28 days, by nest location (1 vs 2) and nest type (Real vs Artificial).

3.4.2 Mayfield Estimator/Proportions

Table 3.4. Daily survival rate, probability of surviving 28 days and 95% CIs using mayfield estimator for real nests.

	Daily survival rate, s	prob(survive 28 days), = s**28	95% Conf Interval	
Colour			**Lower**	**Upper**
Green	0.940928	0.181795	0.132693	0.230898
Cream	0.97355	0.472102	0.427966	0.516237
Location				
1	0.9872	0.698	0.6472	0.7488
2	0.9441	0.1999	0.1621	0.2377

Table 3.5. Apparent nest success and 95% CIs for artificial nests.

	proportion(survive 28 days)	95% Conf Interval	
Colour		**Lower**	**Upper**
Green	0.222222	0.0624	0.382
Cream	0.72	0.5404	0.8996
Location			
1	0.8182	0.6727	0.9637
2	0.3902	0.2062	0.5742

For wax egg colour the Mayfield estimator results bare out the same comparison as the logistic exposure model. The nests with cream wax eggs had higher survival than those with green wax eggs for both real Banded Dotterel nests and artificial nests (Figure 3.10). This is also the case for the location factor where location 1 has the significantly higher survival rate than location 2 for both real Banded Dotterel nests and artificial nests (Figure 3.11). As with the logistic exposure model comparing the Mayfield estimate of nest survival at real nests against the 'apparent nest success' of artificial nests there is no significant difference (Figure 3.12).

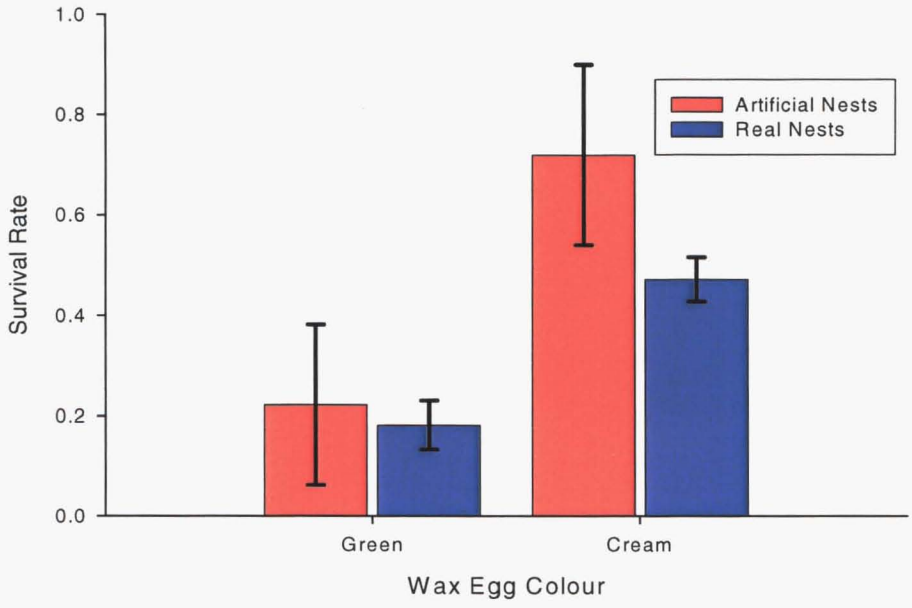

Figure 3.10. Proportion of nests which survived for the cream and green wax eggs in artificial nests and the Mayfield estimator of survival for cream and green wax eggs in real nests. CI's = 95%.

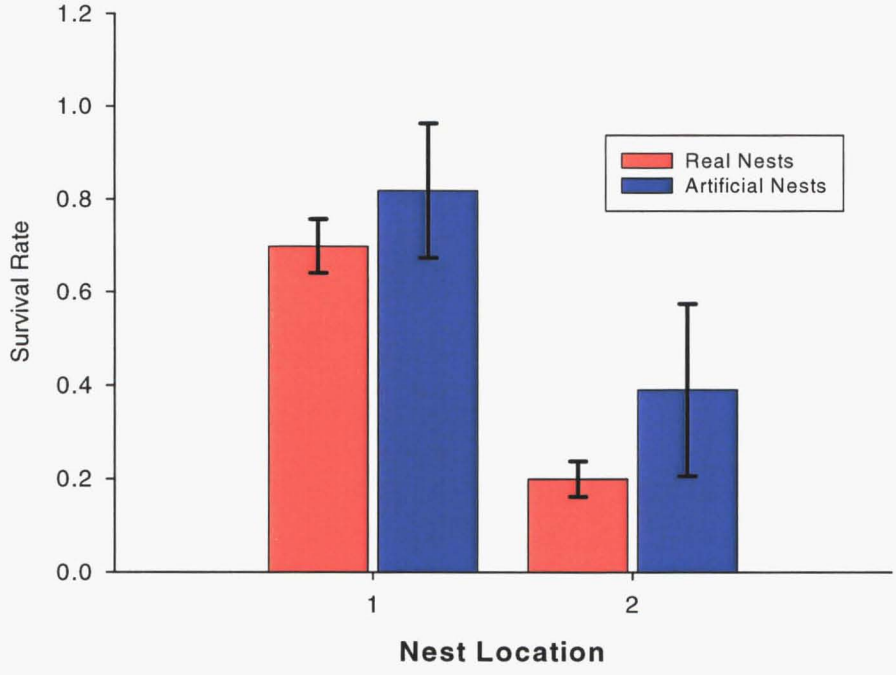

Figure 3.11. Proportion of nests which survived in locations 1 and 2 in artificial nests and the Mayfield estimator of survival for real nests in locations 1 and 2. CI's = 95%.

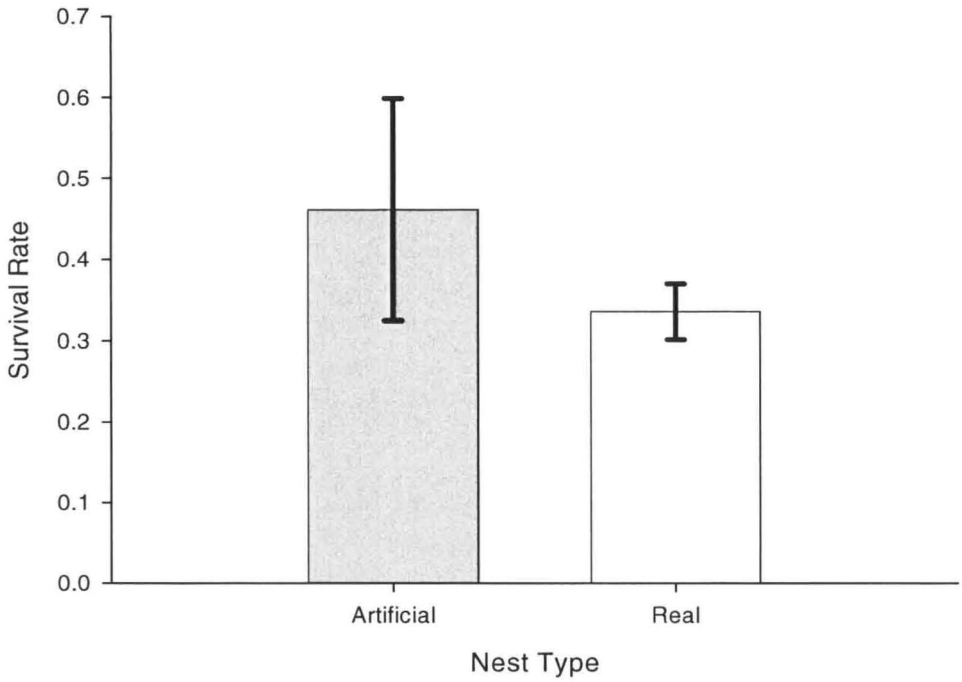

Figure 3.12. Mayfield estimate results for the real nests vs the proportion of artificial nests which survived. CI's = 95%

The logistic exposure model gives slightly higher survival rate estimates than those obtained through the Mayfield method (real nests) and apparent nest success (artificial nests) (Figure 3.13).

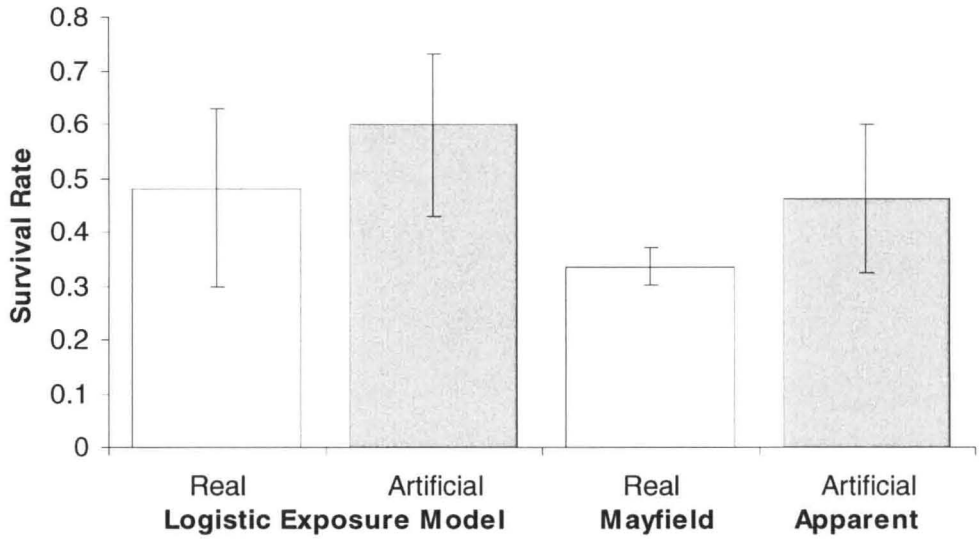

Figure 3.13. Comparison of the survival rates for nest type (Real and Artificial) between the Logistic Exposure Model, Mayfield Estimator and Apparent Nest Success.

3.5 Discussion

3.5.1 Different Predator Suites

There is an implied assumption in studies using artificial nests that they act as a suitable surrogate for real nests. This is often not the case. Our results show that artificial and real nests were subject to different predator suites. Mammalian predators appear to be underrepresented at artificial nests and avian predation overestimated. Recent research has suggested that this may be a primary reason for observed differences in predation rates between real and artificial nests (Willebrand & Marcstrom, 1988; Haegen *et al.*, 2002; Moore & Robinson, 2004; Thompson & Burhans, 2004). Further to this Part & Wretenburg (2002) suggest that artificial nests may only predict the risk for real nests when the predator species are similar at both nest types. However, our results show that predation rates were similar between real and artificial nests despite dissimilar predator suites. Overall survival rate was not significantly different between real (48%) and artificial nests (60%) and significant differences in survival rate between wax egg colour and nest location were evident at both artificial and real nests.

Wilson *et al.*, (1998) suggest that different predators may depredate artificial and real nests and this effect may be compensatory, where overall predation rates are not significantly different however the species responsible differs. This is clearly evident in our results with artificial nests mainly predated by avian predators, whereas a combination of avian and mammalian predators was responsible at real nests. There was no significant difference in overall predation rates between real and artificial nests, indicating a compensatory effect. Other recent studies have found evidence of similar situations (Thompson & Burhans, 2004; Robinson *et al.*, 2005).

Differences between artificial and real nests may be due to predators cuing off behaviour from the parent birds or indeed parent birds defending the nest. Many studies use an 'all purpose' nest and eggs when studying impacts on an avian

assemblage (Major & Kendal, 1996). These authors state 'an experimental setup modelled on a single target species has the greatest likelihood of resembling a natural situation'. I concur with this statement and also their further conclusion that artificial nests should resemble real nests as much as possible. However it should be noted that the ultimate aim is to have an artificial nest setup that incurs predation disturbance at the same rate and with proportionately the same species as real nests. This may not necessarily be an identical mimic of real nests.

Our results show no significant difference between survival rate of real and artificial nests yet a difference in predator species existed further strengthening the argument that calibration is needed between the results of artificial nest studies and the real nests. Differences in predators between artificial and real nests is a common occurrence (Wilson *et al.*, 1998; Buler & Hamilton, 2000; Davison & Bollinger, 2000). These results are usually reported for areas where snakes are major nest predators and snakes have never been observed depredating artificial nests or eating quail eggs in captivity (Roper, 1992; Marini & Melo, 1998; Buler & Hamilton, 2000; Thompson & Burhans, 2004).

The use of artificial nests is unlikely to provide accurate measures of nest predation for a target species. Artificial nest experiments may, under certain controlled conditions, represent a useful approach to address conservation questions; and the development of reliable indirect approaches in general should be encouraged rather than condemned (Villard & Part, 2004).

3.5.2 Wax egg colour (Nest Conspicuousness)

We found that wax egg colour had a highly significant effect on nest survival. Cream wax eggs had a higher survival rate than green ones This effect was more evident in artificial nests than real nests. Within the avian predators there appeared to be a strong preference for the green wax eggs. Avian predators, in particular, demonstrated a preference for green wax eggs may be negated to some degree by the presence of

incubating adults. However a further study of the egg type/colour preferences at artificial nests in 2006 does not show the same degree of 'preference for green wax eggs' (Lyons, unpublished data).

Colour of eggs used in artificial nest studies is not an attribute which has received much attention following some early papers showing no difference between egg colour treatments (Major & Kendal, 1996). A school of thought exists that egg inconspicuousness is an adaptation to reduce predation (Lloyd *et al.*, 2000; Weidinger, 2001a; Aviles *et al.*, 2006). However, it appears this may only be the case in ground nesting birds (Haskell, 1996), as Gotmark (1992a) and Aviles *et al.,* (2006) suggest egg crypsis may be a neutral trait for shrub and canopy nesters. I suggest that when using artificial nests to study nest predation of ground nesting species that consideration must be given to the type of egg used. It appears that the real eggs (quail and chicken) often used in artificial nest studies (Major & Kendal, 1996) are inappropriate for use on braided rivers, due to their conspicuousness resulting in inflated predation estimates (Chapter 2:). The cream coloured wax eggs had a higher survival rate in artificial nests than in real nests, which suggests that cream coloured wax eggs are unlikely to have decreased the survival rate of Banded Dotterel nests (Figure 3.10). Wax eggs with a green base colour had a low survival rate and may not be appropriate for use in monitoring nests survival of braided riverbed birds. This supports Rangen *et al* (2000), which suggested in order to obtain predation patterns similar to real nests the choice of egg type may be critical. Knowledge of the predator assemblage would assist in the appropriate choice of egg types for artificial nest studies (Rangen *et al.*, 2000). Compared with nests of shrub/canopy nesting birds the eggs of ground nesting species may be far more important in determining conspicuousness because the nest can only be seen from above. However for shrub/canopy nesters the nest itself may be more visible than the eggs themselves (Weidinger, 2001a).

The colour vision of Southern Black-backed Gull has not been assessed, however it has been investigated in other related Laridae species. These related species have vision biased towards ultraviolet chromatic ocular disposition (UV COD) (Odeen &

Hastad, 2003). These authors suspected that the bias towards UV COD in gulls may be an adaptation to more effectively spot prey, as gulls prey on fish just below the surface and the effect of underwater UV scattering would be negligible. However it has been suggested that it is 'more probable that this trait is associated with their terrestrial foraging habits rather than piscivory' (Hastad *et al.*, 2005). All six raptor species measured be Odeen & Hastad (2003) showed short-wavelength sensitivity biased towards violet chromatic ocular disposition (VS COD). So it is likely that the Harrier Hawk uses different visual cues than the Southern Black-Backed Gull. This is an important consideration in the development of an artificial interference device technique. The device must be tested to insure that it doesn't bias the likelihood of interference by any particular predator/s. The need to ensure wax eggs do not induce additional avian predation is one of the reasons that wax eggs should not be used on a widespread scale until they can be compared for survival rate of Banded Dotterel nests with wax eggs against unmodified Banded Dotterel nests.

Egg colour and patterning is only one aspect which can affect nests conspicuousness to predators. Olfactory cues may be important for some predator species (Storaas, 1988; Rangen *et al.*, 2000; Villard & Part, 2004). Nest construction could be important, as eggs could be covered with nest material or the nest itself may be well camouflaged (Storaas, 1988). Behaviour of the adult bird may also influence predation, e.g. adult with a cryptic body sits on the nest or alternatively the activity of the adult bird around the nest attracts predators (Storaas, 1988; Wilson *et al.*, 1998).

3.5.3 Wax egg acceptance by Banded Dotterel

The majority of incubating Banded Dotterels accepted the introduction of the artificial wax egg on the first attempt. However of those that did not (20%) some were observed removing the wax egg immediately by grasping the wire loop at the base of the egg and dragging it a short distance away from the nest. It appeared to be important that the presence of the wax egg did not inhibit the adults' ability to incubate the clutch. This required the wax egg to be placed as low in the nest as possible, preferably not protruding higher than the real eggs. It is not clear whether or

not the adult birds perceive the wax egg as a real egg or simply an inanimate object. In one nest the wax egg was moved around in the nest a couple of times and at one nest following a predation event an adult was incubating a wax egg after all real eggs were lost. So there is some evidence that at least some individuals may have perceived the wax egg as one of their own. The video clip (enclosed CD) includes some footage of an adult dotterels' behaviour on returning to a nest with a wax egg. The incubating adult returns to the nest and settles in a natural manner. The wax egg can initially be seen under the rump and then is completely covered when the adult repositions. The video clip is 45 seconds pan of habitat, 2 minutes 45 seconds of adult returning and incubating on a wax egg, 35 seconds of an adult on a nest without wax egg and 30 seconds of banded dotterel defensive display (broken wing).

3.5.4 Reasons for nest failure on the Waimakariri River

Larus spp. are common nest predators of tern and plover species (DeVault *et al.*, 2005; Ivan & Murphy, 2005). The results show the major predator in the Lower Waimakariri to be avian (most likely Southern Black-backed Gull, but possibly Harrier Hawk). This result differs from that of the Upper Waitaki Basin video monitoring which found that although Harriers and Black-Backed Gulls are abundant in the Upper Waitaki Basin '*avian predators are not major egg predators in braided rivers*' (Sanders & Maloney, 2002). This may be a methodological concern regarding the use of video cameras and is discussed below.

The proportions of the other nest predators observed in this study differ markedly from those observed in the Waitaki Basin (Sanders & Maloney, 2002). Although their results combine Banded Dotterel, Black-fronted Tern and Black Stilt nests the vast majority of nests were of Banded Dotterel and their results show cats were responsible for 42.9% of predation. Cats were not identified in the present study as nest predators. However they may have been responsible for interference at nests recorded as possible mammal. The amount of hedgehog predation in the present two studies is similar but the level of ferret predation is much lower in the lower Waimakariri.

Hedgehogs were identified as the major mammalian nest predator in the study sites. Although not the primary mammalian predator in the Waitaki Basin they were responsible for 20% of nest predation events (Sanders & Maloney, 2002). A similar situation has been studied in the Western Isles of Scotland (Jackson, 2001). The European hedgehog is also an introduced nest predator of wading birds in this region. Exclosure plots were used to determine whether control of hedgehog predation would increase nest survival or would result in compensatory predation by native avian predators. Nest success within the exclosure plots was approximately 2.4 times that in the control areas and there was no evidence of any compensatory predation (Jackson, 2001). It is likely the hedgehog control would be an effective management strategy to enhance nesting success of wading birds in braided riverbeds. In particular for colonial nesting species such as black-fronted tern whom not only lose nests to hedgehogs but may desert entire colonies following hedgehog disturbance (Keedwell, 2005). Although exclusion fencing is not viable in the braided riverbed context trapping and poisoning may greatly reduce hedgehog densities.

A significant difference in predation rate was observed between the two study locations. Location 1 had a higher survival rate than Location 2 and both artificial and real nests showed this pattern. I suggest that a possible reason for this difference is that there are less Black-backed Gulls in Location 1. Black-backed Gulls on the Waimakariri River nest in large colonies and the nature of the river in Location 1 differs from that which existed in the past. The restriction of the river through stopbanks and the extraction of gravel may be making the stretch of river in Location 1 unsuitable for the gulls. It should be noted that the 2005 populations of Black-backed gulls in the study areas was lower than observed in the past (Crossland, pers comm.). Therefore predation pressure from gulls may have been even higher in the past. The impact of Black-backed Gulls on other riverbed nesting species needs further investigation. It is possible they have a similar effect as weed invasion in that they restrict suitable nesting habitat for other species.

Another factor may be that the high level of human activity in Location 1 may actually deter predator species. Although high levels of human activity may deter

nesting birds as much if not more than nest predators. Banded Dotterel and Black-fronted Tern nests were located in areas with high human activity, however, no Wrybill or Black-billed Gull nests were found in these areas.

The presence of vehicles on braided riverbeds is commonly cited as a threat to nesting birds. Three artificial nests were run over suggesting that the problem does exist to some degree. It would appear that for the Banded Dotterel at least it is rare that a nest is ever actually physically run over by a vehicle. Vehicles pose more of a threat to nests by people parking for long periods in the incubating adults perceived threat range. This can cause the adult to stay off the nest for too long and the eggs failing due to thermal stress. The more extreme the ambient temperature the shorter an adult can be off the nest before it will fail. The threat posed by vehicles can be reduced by making drivers conscious of the effect their behaviour may have and educating them on ways to mitigate their effect (e.g. good route choice). Vehicles are likely to have a larger impact on species nesting in dense colonies (Black-billed Gull, Black-fronted Tern, Black-backed Gull), a total vehicle ban in these colonies may be appropriate. However further research to quantify the impact of vehicles on braided riverbed birds is needed. Black-fronted Terns are believed to be the most susceptible to colony abandonment due to disturbance, however a large colony hatched some chicks in a high disturbance region on the Waimakariri River in 2005 (M^{c}Entee, pers. Obser.).

The river flows in braided rivers of the east coast of the South Island fluctuate dramatically following rainfall in the upper catchments. Due to this nests in braided rivers are under threat from flooding. However during the three months I was monitoring nests the river level was relatively consistent and only one nest being monitored was swamped by floodwater during what could only be described as a moderate fresh. It is likely that in other years flooding would have resulted in the loss of more nests.

3.5.5 Other nest monitoring methodological issues

3.5.5.1 Wax

In most cases the impressions left on the wax eggs were sufficient to allocate the predation event into a predator guild (avian vs mammal). In a small number of cases marks could be attributed definitively to Black-Backed Gulls or Hedgehogs. This is because these species have the potential to leave very distinctive impressions. This fits with the conclusion of Svagelj *et al.*, (2003) that paraffin-filled eggs were not adequate to identify predator species although predators could be assigned to broad groups.

There was no evidence of wax eggs being damaged in Banded Dotterel nests for reasons other than predation. However the wax eggs used in artificial nests were usually totally exposed to the sun. This exposure meant on the hottest days of November 2005 some of the wax eggs suffered from 'weeping', where they became sticky to the touch. Sand then had a tendency to stick to the wax eggs altering their appearance. Also in some cases air bubbles under the surface of the wax expanded causing small lumps on the egg surface. This type of wear and tear may affect the wax eggs ability to provide good quality predator impressions. However it should be noted that wax eggs exhibiting this type of wear and tear had been in the field longer than the 30 day cut off used in the analyses.

3.5.5.2 Nest Monitoring with Cameras

Although the use of video or still cameras may have the best chance of positively identifying a predator species it may not provide the unbiased estimates of predation desired. It is possible that predators may use the presence of cameras to detect nests. Yahner & Wright (1985) observed avian predators learning to associate hair catches for mammalian predators with the presence of nests. However the opposite effect has

also been observed where Buler & Hamilton (2000) found that cameras initially deterred predators from artificial nests (first trial) and caused an overall reduction in predation at real nests. Video cameras have been used to try and record passerine behaviour when they come into contact with toxic baits for pest control. Native passerines such as the New Zealand Robin (*Petroica australis* Sparrman) and New Zealand Tomtit (*Petroica macrocephala* Gmelin) were found to be very shy of cameras and would not approach food when cameras were present. However introduced passerines accustomed to human activity were not camera shy (Ross, pers comm.). This has important implications for previous nest monitoring work of braided riverbed birds. As the historical work conducted by Sanders & Maloney (2002) used video cameras as their only monitoring tool it is possible that some camera shy predators were not recorded. I suspect that this may be a significant contributing factor to the high number of avian predators recorded in my study as opposed to the low numbers in Sanders & Maloney (2002). The potential avoidance of avian predators to the presence of nest monitoring cameras needs consideration.

3.5.5.3 Sign at nests

The use of 'sign' (using observations about the state of a nest following a predation event) at nests to identify predators suffers from major constraints through inter-specific overlap and intra-specific variation in the way nests are depredated (Lariviere, 1999; Part & Wretenberg, 2002). In other words, numerous predator species share similar patterns of nest predation and individuals of the same species may destroy eggs using several different methods. It is rare that prior to studying nest predation in a new area the full predator suite can be identified. This is important as to infer predation from sign at nests first the potential predators and their typical sign must be known. Further complicating the matter in braided rivers is that it is not uncommon for the nest bowl to be cleaned by the nesting adults following a predation event, making accurate inference from sign at nests exceedingly difficult. Lariviere (1999) strongly urges that the technique be abandoned and research focus on developing predator-identification devices. Despite strong criticisms, studies trying to test the utility of sign at nests interpretation continue, and draw similar conclusions

that using sign at nests it identify predators is simply too unreliable (Pietz & Granfors, 2000; Staller *et al.*, 2005).

I have demonstrated here that no silver bullet exists for monitoring of nest predation. Many techniques have been evaluated in the literature and there is invariably evidence for and against. Therefore one should keep an open mind when determining a nest predation monitoring strategy.

Chapter 4: General Discussion

4.1 Introduction

Artificial nest studies have made a considerable contribution to our understanding of nesting biology. However, the rigour of many studies and the integrity of many results and conclusions may be deficient at best (Willebrand & Marcstrom, 1988; Major & Kendal, 1996; Part & Wretenberg, 2002; Thompson & Burhans, 2004). Ideally an 'experimental nest' can be used to replicate the real nest of a target species or substitute for an assemblage of species and that predation rates and predator species will approximate those of the target species. The majority of artificial nest studies use wicker baskets (often a poor mimic of natural nests) as artificial nests and quail eggs as surrogates, usually to assess predation on passerine species (Major & Kendal, 1996).

Artificial nests are used because they are easy to use and are adaptable for experimental manipulation. However an ever-increasing body of literature is revealing deficiencies in the method. The predation rate at artificial nests rarely reflects that at real nests accurately. Also in many cases the predator species responsible differs between real and artificial nests.

Artificial nests are invariably used in conjunction with a device to record predator interference such as video cameras, still cameras, hair traps, tracking tunnels or wax blocks. In the past two decades a considerable quantity of research has been published which uses interference devices to assess nest predation. Each technique has a contribution to make to the study of nest predation. Consideration of the circumstances of the study should guide the technique used. In this study the desire was to test the use a microcrystalline wax eggs as the interference device. The high risk of flooding and vandalism in this environment precluded the use of expensive equipment and a technique that could be used directly at the nest was desired.

Microcrystalline wax was chosen because it is less brittle than paraffin wax, sometimes used to obtain predator bite marks, and has a low palatability. These factors make microcrystalline wax an excellent material to use where predator identification is desired (Thomas *et al.*, 2003).

4.2 Research findings/implications

Trial 1 used quail eggs to create a stimulus for predators. However the results from Trial 1 and subsequent trials showed that when quail eggs were used the predation rates were unrealistically high. During Trial 1 all nests containing quail eggs were interfered with over the first two days. When the egg shells remained there was a consistent pattern of damage which was that the eggs had been penetrated from above while on the ground. This is commonly associated with avian predation. In addition fresh avian scat was present at six nests. The wax eggs used in Trial 1 were dyed pale green in an attempt to mimic the colour of real Banded Dotterel eggs, although no cryptic patterning was applied as exists on real eggs. Trial 1 was also used to assess the need for a restraint (tying to an 'anchor') to prevent removal of the wax egg. Thirty six wax eggs were lost from the untied treatments and only 13 from the tied treatments, suggesting that tying down would be beneficial and the practice was adopted throughout the rest of the study.

During Trial 2 most of the wax eggs were lost despite being tied down. The primary identifiable reason for this was failure of the tie down. This was addressed subsequently by using higher breaking strain monofilament and being more careful with 'anchor' selection. Trial 3 found avian predators likely to be the cause of 100% predation of quail eggs at 16 artificial nests over the first monitoring interval (2 days). At this point two major changes were made to the methodology; quail eggs were no longer used as they appeared to 'over stimulate' predators, and the wax eggs were painted with a pale green base colour, and cryptic splotches of brown and black added to increase the similarity to Banded Dotterel eggs. Previously paint had not been used due to concerns that it may cause a smell that could influence predation.

Trial 4 compared the cryptically-painted wax eggs against a control treatment of chicken eggs and found that painted wax eggs resulted in low interference rates while the chicken eggs resulted in the similar high predation rates observed previously. The combination of all of these results suggests that avian predation pressure is higher on poorly camouflaged eggs and nests. The results also serve to highlight that in some situations the type of egg used in the artificial nest may have an impact on the predation rates and predator species.

During the 2005 nesting season of Banded Dotterel on the Waimakariri River the potential of wax eggs as a device to measure interference was assessed, and whether predation on artificial nests accurately reflected that of real nests. Fifty-eight real nests and 52 artificial nests in two areas were monitored, using two wax egg types to record and identify predators. Wax eggs were accepted by the majority of incubating adults and were seldom left unmarked following a predation event. Impressions in the wax usually only enabled predation to be assigned to a predator group rather than species.

In this study there was no significant difference between the predation rates at real and artificial nests however the predator species composition differed. Artificial nests were mainly predated by avian predators and at the real nests a combination of avian and mammalian predators were recorded. It is possible the observed difference may occur as a result of the presence of incubating adults stimulating mammalian predator interest. Despite different predator suites artificial nests showed similar predation effects of nest location and wax egg type on survival rate relative to real nests. Mammalian predators were underrepresented at artificial nests and avian predators overrepresented. The results suggest that careful consideration should be given to the applicability of artificial nests in each unique situation. At the very least in studies involving a target experimental species the results from artificial nests must be verified/calibrated with real nests. However, the use of artificial nests may be appropriate and should not be discounted in situations where the identification of

predator presence is the objective, without any specific relationship being drawn to a target prey species.

The egg type used in the artificial nest was likely to have an impact on the rate of predation and the species recorded. When real eggs were used (chicken and quail) depredation rates were unrealistically high. Predators also readily interfered with wax eggs which were dyed a flat pale green. This demonstrates the need to consider the effect the type of egg may have on interference rates in nest predation studies for ground nesting species. In tree nesting situations the nest itself may be more visible than the eggs, therefore, artificial nest design may be of utmost importance. Whereas, egg conspicuousness may be the most important factor for ground nesting species, making egg design/type of utmost importance (Weidinger, 2001b).

4.3 Management Implications

4.4 Endangered Species

The endemic avian fauna of the South Island's braided rivers has evolved in the absence of mammalian predators. This has left several species in severe threat from predation. High predation rates and low fledging success in Banded Dotterels (the most ubiquitous species) suggest that introduced predators may be a major cause of declines in range and abundance of braided riverbed birds (Rebergen *et al.*, 1998; Sanders & Maloney, 2002). Despite this Banded Dotterel are not considered to be in significant decline (Pierce, 1999). Features of the most highly-endangered species, the Black Stilt, which make it susceptible to predation are; side-stream nesting habitat, high site fidelity, poor distraction displays, solitary nesting, high chick-adult distances and slow growth rates in chicks (Pierce, 1986). Video monitoring has identified cats, ferrets and hedgehogs as the main cause of mortality at Banded Dotterel, Black-Fronted Tern and Black Stilt nests in the Upper Waitaki Basin, with Stoats, Harriers and Magpies also contributing to a small degree (Sanders & Maloney, 2002). Our research suggests avian predators exert a high predation pressure which has lead to

adaptations for avoiding avian predation. Such as cryptic nest and egg colouration and defensive behaviours like the broken wing display. Any egg type I used to monitor interference that did not have a high degree of camouflage was interfered with at a very high rate. The cryptic nature of Wrybill, Black-fronted Tern and Banded Dotterel nests and eggs is likely an adaptation to this avian predation pressure. Therefore, it may be that birds do not depredate eggs a great deal in the field because of these adaptations, however, predatory birds are there and causing predation in some areas. These results and the results of other studies serve to highlight that the impact of these predators can be highly variable. I have shown how a highly disturbed (human disturbance) study area in the lower Waimakariri river had significantly higher nest survival than another study area 9 km upstream with low human disturbance. Pierce (1987) found predation rates at Banded Dotterel nests were significantly different between areas adjacent to rabbit poisoning operations (high predation) and non poisoned areas (low predation). This evidence suggests that increased predation may occur as a result of prey switching by predators due to the decrease in rabbits following poisoning operations. This is a further example of the need for reliable information on the relative impacts of predator species to effectively target control of predators and management of threatened species.

Keedwell (2005) concluded that nocturnal disturbance and predators are likely to be the primary cause of nest desertion in Black-fronted Tern colonies. Introduced mammals are likely to be the largest contributor to nocturnal disturbance whether they are predators, e.g. cats, or non predators, e.g. rabbits. Nest predation rates at Black-fronted Tern colonies in the Waitaki Basin varied from 1% to 97% (Keedwell, 2005). Video evidence showed that five cats, 11 hedgehogs and a ferret were responsible for 17 videotaped predation events (Keedwell, 2005). This serves to highlight the impact of introduced predators on Black-fronted Tern colonies and the need for active management. Wax eggs may have potential to identify predator species of nests lost to predation. The Black-fronted Tern is considered globally endangered with population estimates less than 10000 individuals (Keedwell & Sanders, 2002; Keedwell, 2005). This population size is very much an estimate and more accurate population data and survival data is required to better assess the status of this species.

The use of wax eggs and artificial nests may be a useful tool to aid research on this species in the future.

Most waders, gulls and terns will not nest in areas of significant upright vegetation growth. Riverbed islands which lack substantive plant growth have higher breeding success for birds than heavily vegetated islands. Vegetation-free islands do not support prey species, nor do they afford camouflage for introduced mammals so their impact on nesting birds is less. The habitat of braided rivers is maintained through a high disturbance regime which regulates the vegetation. Common scabweed (*Raoulia hookeri*) and other highly specialised ground cover plants were the original vegetation. The construction of hydro-electric power schemes has led to silt accumulation which allows trees, herbs and grasses to invade. This exotic vegetation makes unsuitable habitat for breeding waders and potential nesting habitat increasingly prone to predation (Balneaves & Hughey, 1990; Rebergen *et al.*, 1998). The exotic weeds of concern are Russell lupin (*Lupinus polyphyllus* 'Russell'), Tree lupin (*Lupinus arboreus* Sims), Gorse (*Ulex europaeus L.*), Broom (*Cystisus scoparius L.*), and Willow (*Salix spp L.*). The relative importance of these species varies between river systems. This increase in weedy vegetation has reduced available nesting habitat and forces birds to nest at a lower cross-sectional level in the river making either nests more susceptible to flooding and increasingly prone to predation from mammals (Balneaves & Hughey, 1990). For the reasons mentioned above the nature of the braided river ecosystems are being altered and knowledge of these effects on wildlife is desirable. One aspect of the changing ecosystem is the effect on nest predation. Wax eggs and artificial nests may provide a useful tool for assessing the response of nest predation to the changes mentioned above.

4.5 Wax eggs

The present study is a positive first step in analysing the utility of wax eggs as a tool to identify nest predators in the braided rivers of the eastern South Island. However, further research and refinement is required. Microcrystalline wax is already used as a

predator monitoring device, so there is a precedent for it's use (Thomas, 1999; Thomas *et al.*, 1999; Thomas *et al.*, 2002b; Thomas *et al.*, 2003; Thomas, 2005b). This work is not the first attempt to use microcrystalline wax for monitoring nest predation (Whyte *et al.*, 2005).

The results of this study suggest that the type and colour of egg used in the artificial nest will have a significant affect on interference rates. It is presumed that a major function of egg colour is protection from visually-oriented predators (Wilson *et al.*, 1998) and Yahner & Mahan (1996) conclude that 'colour rather than egg size was the major factor influencing nest disturbance in our study'. However, Major & Kendal (1996) provide examples of studies which found egg colour did not influence predation. Also Mezquida & Marone (2003) argue that recent studies show that colour is not an important consideration. The results of the present study suggest that colour should be given a high level of consideration in the continued development of wax eggs as an interference device. Although the results of my study indicate an effect of wax egg colour the exact nature of that effect is not clear. The colour effect could have been that green wax eggs were more likely to be predated than a natural nest or perhaps that cream wax eggs reduced the likelihood of predation. Therefore, both wax egg colours used during the 2005 breeding season (cream and green) should be trialled against a control group of real Banded Dotterel nests with no wax egg added, to determine the effect of colour on the predation rate of nests.

4.6 Future Research

This research has highlighted the need to test interference device type, in this case egg characteristics, to determine that which is most suited to the situation. The major next step would be to test the painted wax eggs against a control group of Banded Dotterel nests to determine whether or not the introduction of a wax egg changes the likelihood of survival for nests. In such a study the minimum treatments would be, a group of Banded Dotterel nests with a painted wax egg added and a control group of nests without wax eggs added.

Also some definitive observations of predator response to wax eggs in nests are needed. Definitive evidence could be achieved using video cameras at both real and artificial nests. Evidence from video could provide further confirmed field examples of the predator imprints on wax that could be used in future identification from wax eggs. It would also help to determine whether it was Black-backed Gulls (as suspected) that were responsible for the avian predation.

A spin-off question has arisen regarding the effect the presence of video cameras may have on predators, in particular avian predators. Avian predators were commonly recorded in this study but rarely in a video monitoring study (Sanders & Maloney, 2002). It should be reasonably straight forward to test whether or not the gulls would avoid cameras by setting up artificial nests with a variety of egg types in the vicinity of a Black-backed Gull colony, some with and some without a camera set up over them and record the interference. A mimic of a video camera (not an actual video camera) could be all that is required.

Once the technique of using a painted wax egg in a real nest can be definitively proven not to increase the likelihood of predation at a nest then there is potential for this technique to be trialled on other species. The Wrybill is an endangered species and is fairly similar to a Banded Dotterel and it is suspected that a major threat to this species is nest predation. Two other threatened species, the Black-fronted Tern and the Black-billed Gull, that nest on braided rivers could also be candidates for the use of artificial wax eggs to identify their nest predators. These species are colony nesters as opposed to the solitary nesting Wrybill and Banded Dotterel.

There may be other riverbed areas that are more suitable for conducting some of this research. Those that spring to mind are the north branch of the upper Ashburton River just below the Maori Lakes on the true left, where there is a large area of habitat for Banded Dotterel and where large numbers have been recorded (O'Donnell & Moore, 1983, M^{c}Entee, pers. Obser.). This area is accessible from a road and less prone to large floods preventing access. The Rakaia River is probably the most suitable river

to study Wrybill. Where studies would involve the use of expensive camera equipment the rivers of the Waitaki Basin are probably best suited as the flows are more consistent due to the dams for power schemes. The unpredictable nature of the river flows is the major difficulty with braided riverbed research. This study benefited from a season of stable low flows in the Waimakariri River during late 2005. The Waimakariri Rivers' extreme flow variability in late 2006 would have caused severe disruption to the type of research in this thesis.

This research has provided evidence that the use of microcrystalline wax eggs to measure nest predation has potential. The cause of Banded Dotterel nest failure could be determined as predation using the marks left on wax eggs. The predator marks on the wax eggs were often able to be categorised into avian or mammalian and in some instances predator species could be judged. The comparison between artificial nests and real nests further highlighted a problem with artificial nest studies. The predation rate at artificial and real nests may not be different, however, the relative contributions of the predators differs. The results of this research should make a strong contribution to the literature on the use of microcrystalline wax in interference devices in New Zealand ecosystems. The suite of predators unique to the braided rivers of New Zealand and their interaction with in some cases naïve prey species create a need for creative research and conservation. The use of microcrystalline wax is an example of a creative approach to research in a challenging environment.

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Appendix 1 (CD Appendix)

Contents

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Chapter 3 Raw data	Raw data chapter 3.xls
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